Ontario Geological Survey
Study 28

Talc, Magnesite and Asbestos Deposits in the Timmins – Kirkland Lake Area
Districts of Timiskaming and Cochrane

by Ulrich Kretschmar and Dianne Kretschmar

1986

Ontario
Ministry of
Northern Development
and Mines

René Fontaine
Minister
George Tough
Deputy Minister

©1986 Government of Ontario
ISSN 0704-2590
Printed in Ontario, Canada
ISBN 0-7729-0924-5

Publications of the Ontario Geological Survey, Ministry of Northern Development and Mines, are available from the following sources. Orders for publications should be accompanied by cheque or money order payable to the *Treasurer of Ontario*.

Reports, maps, and price lists (personal shopping or mail order):

Public Information Centre, Ministry of Natural Resources
Room 1640, Whitney Block, Queen's Park
Toronto, Ontario M7A 1W3

Reports and accompanying maps only (personal shopping):

Main Floor, 880 Bay Street
Toronto, Ontario

Reports and accompanying maps (mail order or telephone orders):

Publications Services Section, Ministry of Government Services
5th Floor, 880 Bay Street
Toronto, Ontario M7A 1N8
Telephone (local calls) 965-6015
Toll-free long distance 1-800-268-7540
Toll-free from Area Code 807 0-ZENITH-67200

Canadian Cataloguing in Publication Data

Kretschmar, Ulrich, 1941- .
Talc, magnesite and asbestos deposits of the Kirkland Lake – Timmins area, districts of Timiskaming and Cochrane
(Ontario Geological Survey study, ISSN 0704-2590 ; 28)
Includes index.

ISBN 0-7729-0924-5

1. Talc—Ontario. 2. Magnesite—Ontario. 3. Asbestos—Ontario. I. Kretschmar, Dianne. II. Ontario. Ministry of Northern Development and Mines. III. Ontario Geological Survey. IV. Title. V. Series.

QE191.K73 1985 553.6'7'0971314 C85-093048-0

Every possible effort is made to ensure the accuracy of the information contained in this report, but the Ministry of Northern Development and Mines does not assume any liability for errors that may occur. Source references are included in the report and users may wish to verify critical information.

Parts of this publication may be quoted if credit is given. It is recommended that reference be made in the following form:

Kretschmar, Ulrich, and Kretschmar, Dianne
1986: Talc, Magnesite and Asbestos Deposits in the Timmins – Kirkland Lake Area, Districts of Timiskaming and Cochrane; Ontario Geological Survey, Study 28, 100p.

1000-86-MARACLE

Foreword

The search for and development of industrial mineral deposits in northern Ontario is an important means of diversifying the mineral economy. The study of talc, magnesite and asbestos deposits, one of several projects in the Northern Industrial Mineral Studies Program, was initiated with the purpose of advancing the industrial mineral industry in northern Ontario.

In this project, ultramafic rocks of the Timmins - Kirkland Lake area have been studied in the context of the geology of the area. A special attempt has been made to relate their content of industrial minerals, e.g. talc, magnesite and asbestos, to their place in the geological framework. By describing the mode of occurrence in several deposits and by analysing the mineralogical detail the authors have been able to provide insights in the origin of mineralization which will be useful in exploration for additional deposits and in their beneficiation.

V.G. Milne
Director
Ontario Geological Survey

Contents

Abstract 2
Introduction 3
  Acknowledgments 3
Archean Talc, Magnesite and Asbestos as Industrial Minerals 4
Deposits of the Timmins Area 6
  General Geology 6
  Stratigraphic Position of Talc, Magnesite and Asbestos Deposits 7
  Canadian Magnesite Mines Magnesite-Talc Deposit, Deloro Township 7
    Economic Geology 9
    Geology 11
    Mineralogy and Chemistry 13
    Discussion 21
  Allerston Talc-Magnesite Deposit, Whitney Township 22
    Economic Geology 23
    Geology 23
      Volcanic Rocks 23
      Iron Formation 25
      Komatiitic Rocks 25
      Intrusive Rocks 25
      Structure and Metamorphism 25
    Mineralogy and Chemistry 26
    Discussion 35
  Daffodil Asbestos Deposit, Deloro Township 36
    Economic Geology 36
    Geology 36
    Mineralogy and Chemistry 38
    Discussion 39
  Slade-Forbes Asbestos Deposit, Deloro Township 43
    Economic Geology 43
    Geology 43
    Mineralogy and Chemistry 43
    Discussion 46
Deposits of Midlothian Township 47
  General Geology 47
  Stratigraphic Position of the United Asbestos Deposit 47
  United Asbestos Deposit, Midlothian Township 47
    Economic Geology 48
    Geology 48
    Mineralogy and Chemistry 49
    Discussion 49
Deposits of Munro, Harker and Garrison Townships 53
  Regional Geology and Stratigraphic Position of the Asbestos Deposits 53
  Hofmann Asbestos Deposit, Harker Township 53
    Economic Geology 53
    Geology, Mineralogy and Chemistry 54
    Discussion 54
  Garrison (Bird-Ginn) Asbestos Deposit, Garrison Township 57
  Munro Asbestos Deposit, Munro Township 60
    Economic Geology 61
    Geology, Mineralogy and Chemistry of Area I 61
    Geology, Mineralogy and Chemistry of Area II 66
    Discussion 66

Geochemistry and Alteration Processes 70
Komatiite Geochemistry 70
Field Relations 70
Serpentinization and Asbestos Formation 72
Talc and Magnesite Formation 73
Bulk Chemistry and Loss of Constituents 74
Opaque Minerals and Magnesite Compositions 74
Carbon and Oxygen Isotope Data 75
Composition and Source of Fluid and Timing of Alteration 77
Conclusion 78
Guidelines for Exploration 79
Appendix A — Electron Microprobe Data 80
Appendix B — Analytical Methods for Carbon and Oxygen Isotopes 82
Appendix C — XRD and Staining Methods for Magnesite Determination 83
References 84
Index 88

FIGURES

1. Location of talc, magnesite and asbestos deposits studied 2
2. Location map of Timmins area deposits 6
3. Distribution of stratigraphic units in Timmins area 8
4. Claim map of Canadian Magnesite Mines Limited property 9
5. Geology and sample locations, Canadian Magnesite Mines magnesite-talc deposit ..... Chart A, back pocket
6. Geological cross-section through Canadian Magnesite Mines magnesite-talc deposit 10
7. Jensen cation plot of chemical analyses of whole-rock samples from Canadian Magnesite Mines deposit 20
8. Claim map of Allerston talc-magnesite deposit, Whitney Township 22
9. Geology and sample locations, Allerston talc-magnesite deposit ..... Chart A, back pocket
10. Geological cross-section of Allerston deposit 24
11. Jensen cation plot of chemical analyses of whole rock samples from Allerston talc-magnesite deposit 34
12. Claim map of Daffodil asbestos deposit, Deloro Township 37
13. Geology and sample locations, Daffodil asbestos deposit Chart A, back pocket
14. Jensen cation plot of chemical analyses of whole-rock samples from Daffodil asbestos deposit 42
15. Geology and sample locations, Slade-Forbes asbestos deposit 44
16. Jensen cation plot of chemical analyses of whole-rock samples from Slade-Forbes asbestos deposit 46
17. Geology and sample locations, United asbestos deposit, Midlothian Township ..... Chart B, back pocket
18. Jensen cation plot of chemical analyses of whole-rock samples from United asbestos deposit 52
19. Geology and sample locations, Hofmann asbestos deposit, Harker Township ..... Chart B, back pocket
20. Jensen cation plot of chemical analyses of whole-rock samples from Hofmann asbestos deposit 56
21. Geology and sample locations, Garrison (Bird-Ginn) asbestos deposit ..... Chart B, back pocket
22. Jensen cation plot of chemical analyses of whole-rock samples from Garrison asbestos deposit 59
23. Generalized geology, Munro Mine and vicinity 60
24. Cross-section through Munro A orebody 62

25. Geology and sample locations, Munro asbestos deposit, Area I 63
26. Jensen cation plot of chemical analyses of whole-rock samples from Munro asbestos deposit 66
27. Geology and sample locations, Munro asbestos deposit, Area II 69
28. Al_2O_3 vs $FeO^*/(FeO^* + MgO)$ plot for asbestos-bearing differentiated sills and Dundonald tholeiitic sill 71
29. Carbon and oxygen isotopic compositions 76

TABLES

1. Chemical analyses and norms of whole-rock samples, Canadian Magnesite Mines deposit 14
2. Modal analyses of whole-rock samples, Canadian Magnesite Mines deposit 16
3. Microprobe analyses of opaque minerals in magnesite samples, Canadian Magnesite Mines deposit 17
4. Microprobe analyses of carbonate in magnesite and other samples, Canadian Magnesite Mines deposit 18
5. Trace element concentrations in iron formation samples from Canadian Magnesite Mines deposit 19
6. Mineralogy of four most common rock types at Canadian Magnesite Mines deposit 19
7. Average modal composition of talc-magnesite zones, Allerston deposit 26
8. Modal analyses of talc-magnesite rock, Allerston deposit 27
9. Chemical analyses and norms of whole-rock samples, Allerston deposit 28
10. Average composition and variability in norms, Allerston deposit 34
11. Compositional ranges of typical end products of progressive carbonation of dunitic komatiite 35
12. Chemical analyses and norms of whole-rock samples, Daffodil deposit 40
13. Chemical analyses and norms of whole-rock samples, Slade-Forbes deposit 45
14. Chemical analyses and norms of whole-rock samples, United asbestos deposit 50
15. Chemical analyses and norms of whole-rock samples, Hofmann deposit 55
16. Chemical analyses and norms of whole-rock samples, Garrison deposit 58
17. Chemical analyses and norms of whole-rock samples, Munro deposit 64
18. Carbonate alteration in Area I, Munro deposit 66
19. Microprobe analyses of spinel and carbonates, Area I, Munro deposit 67
20. Sequence of veining during alteration of dunite or peridotite 72
21. Carbon and oxygen isotope compositions 75

PHOTOGRAPHS

1. Quartz veining accompanying carbonate alteration, Canadian Magnesite Mines deposit 12
2. Chrysotile asbestos veins interstitial to polyhedral dunitic breccia fragments, Daffodil deposit 38
3. Polyhedral jointing in massive ultramafic komatiite from Lamotte Township, Quebec 39

CHARTS (BACK POCKET)

Chart A — Figures 5, 9, 13.
Chart B — Figures 17, 19, 21.

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS.

CONVERSION FROM SI TO IMPERIAL			CONVERSION FROM IMPERIAL TO SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note. Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in cooperation with the Coal Association of Canada.

Talc, Magnesite and Asbestos Deposits in the Kirkland Lake – Timmins Area

Districts of Timiskaming and Cochrane

Ulrich Kretschmar and Dianne Kretschmar

Consulting Geologists, Severn Bridge, Ontario.

Manuscript approved for publication by the Chief Geologist, Ontario Geological Survey, September 8, 1982. This report is published with the permission of V.G. Milne, Director, Ontario Geological Survey.

Abstract

The deposits included in this study are: Canadian Magnesite Mines magnesite-talc deposit, Allerston talc-magnesite deposit, Daffodil asbestos deposit, Slade-Forbes asbestos deposit, United asbestos deposit, Munro asbestos deposit, Garrison asbestos deposit, and Hofmann asbestos deposit. All deposits were geologically mapped, except the Munro deposit.

Petrochemical studies of the ore-hosting ultramafic rocks show that these deposits have komatiitic chemistry and that Canadian Magnesite Mines deposit, Allerston talc deposit, and possibly Daffodil asbestos deposit are hosted by altered dunitic or peridotitic komatiite flows. The other asbestos deposits occur in the basal dunitic part of differentiated komatiitic sills. Serpentinization and asbestos formation probably took place in a stable tectonic environment at low temperature, by means of seawater with a low CO_2 content and under reducing conditions. Shearing, faulting, folding and metamorphism were apparently not important to the formation of asbestos in the deposits studied. Talc and magnesite formation accompanied seafloor alteration of komatiitic flows by seawater high in CO_2 and under oxidizing conditions. Progressive alteration is reflected by pseudomorphing of minerals in the following sequence: serpentine, chlorite, talc and magnesite. Sequential veining accompanying alteration consists of magnetite, asbestos, talc, carbonate and quartz veins.

Permissive evidence that seawater was the main altering fluid is provided by oxygen and carbon isotopic data, and the chemical changes accompanying alteration are delineated through microprobe analyses of oxides and carbonates.

These results lead us to propose a class of talc, magnesite and asbestos deposits that are derived from the alteration of Archean komatiitic ultramafic rocks, have distinct chemical characteristics, and occur in a unique geological environment.

Talc, Magnesite, and Asbestos Deposits of the Kirkland Lake – Timmins Area, Districts of Timiskaming and Cochrane, by Ulrich Kretschmar and Dianne Kretschmar. Ontario Geological Survey, Study 28, 100p. Published 1986. ISBN 0-7729-0924-5.

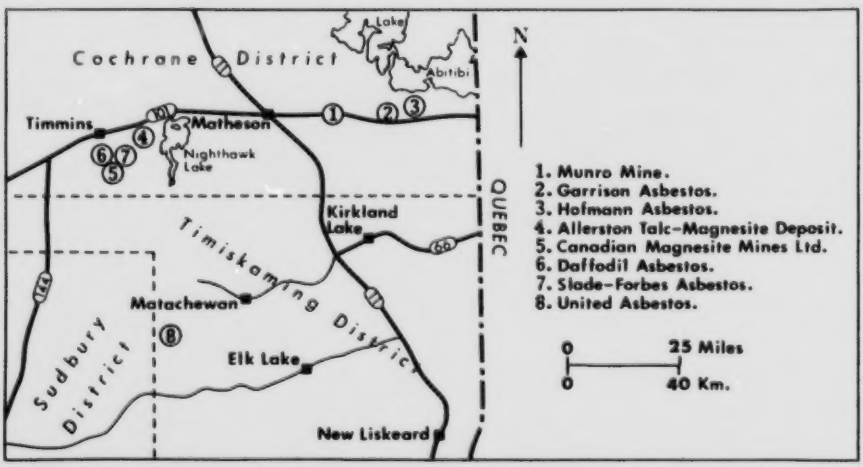


Figure 1. *Location of talc, magnesite and asbestos deposits studied.*

Introduction

The apparently diverse deposit types that constitute the subject of this study, such as talc, magnesite and asbestos deposits, have as a unifying feature their derivation from ultramafic rocks and specifically, from komatiitic ultramafic rocks. The primary purpose of this study was to provide a description of the deposits and to document their chemical affinity as an aid to exploration. Another objective of the study has been to try to identify the conditions that can change an originally dunitic or peridotitic komatiite into an asbestos, a talc or a magnesite deposit as a result of chemical alteration. To this end, we mapped the deposits, studied thin sections, and carried out whole-rock analyses and some stable isotope and microprobe analyses.

The deposits included in this study were chosen because they are producing or formerly producing mines (United Asbestos Mine, Munro Mine), potential producers (Allerston talc-magnesite deposit, Canadian Magnesite Mines magnesite-talc deposit, Daffodil asbestos deposit, Garrison asbestos deposit, Hofmann asbestos deposit), or significant occurrences (Slade-Forbes asbestos deposit). Three other mines in the first category are not included because the owners did not give us permission to study them.

While our understanding of the alteration processes involved has improved as a result of this work, new questions arise and we suggest this study be considered as a stepping stone towards a better understanding of Archean crustal processes.

Preliminary results of our work have been presented in Kretschmar and Kretschmar (1979, 1980). The locations of the deposits are shown in Figure 1.

ACKNOWLEDGMENTS

Complete co-operation and virtually unrestricted access to their voluminous data files were provided by the late Dr. A.T. Griffis of Canadian Magnesite Mines Limited, R.S. Middleton formerly of Rosario Resources Canada Limited (Allerston talc-magnesite deposit), and John Hagan of United Asbestos Incorporated. Ross Hofmann and James Clemenger of Lightval Mines Limited, kindly provided information on the Hofmann asbestos deposit and Terry Howes of Daffodil Asbestos Mines Limited (a subsidiary of Great Northern Pulp & Paper Limited) permitted us to publish information from a private report by Watts, Griffis and McOuat Limited. Permission to map the Munro Mine and the Garrison asbestos deposit (Bird-Ginn) was obtained from John Evelegh, Johns-Manville Canada Incorporated. We wish to thank these individuals for their help, without which this report would not have been possible. Dave Saunders ably assisted with field work and Eric Grunsky, Ontario Geological Survey, helped with computer calculations and data plotting. Special thanks must go to Jim Priest and Joan Thomas who, respectively, drafted the figures and typed the manuscript under severely trying conditions.

Archean Talc, Magnesite and Asbestos as Industrial Minerals

There are features that uniquely characterise Archean talc, magnesite and asbestos deposits derived from komatiitic ultramafics, relative to deposits of these minerals occurring in rocks of younger age. For instance, Archean talc is generally quartz-free (see however Canadian Magnesite Mines deposit), has no tremolite or dolomite associated with it, and is free of both amphibole and chrysotile asbestos. It is platey and non-fibrous in nature and its chemistry is characterized by low calcium, high iron and high nickel. Steetley Talc Limited's Penhorwood Township deposit is the only occurrence of this type of talc that is currently being mined. A potential producer is the Allerston talc deposit in Whitney Township.

Steetley Talc Limited produced about 25,000 short tons of talc products in 1979 from the open pit mine in Penhorwood Township and the mill in Timmins, both of which were acquired in 1978 from Canadian Johns-Manville Company Limited. Reserves are on the order of 8 million tons (Clarke 1979). Most of their product is aimed at the extremely high quality markets, particularly pitch control for pulp and paper manufacturing, but a flash-dried concentrate product, used as filler for ceramics, plastics and parting material in rubber is also produced.

The only other talc producer in Ontario is Canada Talc Industries Limited at Madoc. The company produces a high quality product from its underground mines, which is suitable as a filler for paints and plastics and also pharmaceuticals, cosmetics, plastics and lens polishing (Clarke 1979). The talc occurs in conformable sheetlike talc-tremolite-dolomite bodies which are hydrothermal replacements of Grenville dolomite (Hewitt 1972).

An average of 70,000 tonnes of talc were shipped in Canada each year between 1973 and 1978; most of this was exported to the USA (Clarke 1979). In 1977 average talc prices for ground, bags, carlot f.o.b. mines were $US20-35 (Pearse 1977). In 1980, talc production remained at the 1979 level, at around 60,000 tons, as Canadian producers were unable to displace the 50,000 tons imported for the relatively stable Canadian market of about 100,000 tons (Canadian Mining Journal, February 1981, p.142).

The most important use of magnesia refractories is in lining pneumatic oxygen-steelmaking vessels, electric arc and open hearth furnaces and in ladle linings, and therefore demand is largely tied to the fortunes of the steel industry. The quality of magnesite used in these applications varies considerably but particularly desirable is hard, dense, low-iron magnesite. Such high purity MgO can be produced from seawater or by dead-burning of natural magnesite. Two problems that originally characterized seawater MgO — high boron content and low density — have now been overcome and seawater MgO is making increasing inroads into world markets. MgO from komatiitic ultramafic rocks, e.g. Canadian Magnesite Mines Limited's deposit, is characterized by low CaO and high FeO. There is no known production from the latter type and unless means of reducing the high iron content (on the order of 6 weight percent Fe_2O_3 at Canadian Magnesite Mines deposit) can be found, none can be anticipated.

The only eastern Canadian producer is Canadian Refractories Limited in Kilmar, Quebec, where magnesite of Grenville age occurs in lenticular masses forming partial replacements of marble between hanging wall quartzite and footwall sillimanite gneiss (Spooner 1978).

About 84 percent of the USA's 900,000 tons per annum magnesite consumption is of dead-burned qualities for refractory consumption (Industrial Minerals, September 1977). In 1976, the cost of chemical grade synthetic magnesia was about $US150-172 per ton (Chemical Week, March 24, 1976).

There is a large body of literature dealing with virtually every aspect of asbestos. Some of the most important references are: Ross (1931), Hewitt (1950), Vagt (1976, 1981), Winson (1976), and Wicks (1978). Others are referred to in the sections dealing with specific ore deposits.

Canada is the western world's largest producer of asbestos. The main use of asbestos is in the manufacture of construction materials and therefore markets are

closely tied to housing starts and the general state of the economy. Preliminary figures indicate that total 1980 shipments were 1.3 million tonnes valued at $641.7 million compared with 1979 shipments of 1.5 million tonnes valued at $607 million. Export quantities, generally comprising about 95 percent of production were proportionately lower (Vagt 1981).

Unique aspects of Archean asbestos deposits appear to lie more in the nature of their formation (see below) than in the nature of the asbestos fibre, although the latter is potentially a fruitful avenue of investigation.

Deposits of the Timmins Area

GENERAL GEOLOGY

Locations of the Timmins area deposits are shown on Figure 2. The area has been the subject of numerous investigations and extensive references may be found in the comprehensive study of Pyke (1980), from which the following summary is taken:

> "With minor exceptions, the bedrock of the area is of Archean age. The metavolcanic rocks are divided into two groups, the older Deloro Group and the overlying Tisdale Group; each group is divided into three formations. The Deloro Group is largely composed of calc-alkaline volcanics, about 4500 m thick, and is composed mainly of flows of andesite and basalt in the lower portion and dacitic flows and dacitic and rhyolitic pyroclastics toward the top. Iron formation is common at or near the top of the group. Most of the Deloro Group is confined to a large domal structure in the east-central part of the area. Minor ultramafic flows occur near the base of the Deloro Group and are exposed only in the southwest corner of the area. A major change in volcanism marks the beginning of the Tisdale Group. The basal formation consists largely of ultramafic rocks and basaltic komatiites. This in turn is overlain by a thick sequence of tholeiitic basalts. The uppermost formation is largely volcaniclastic and of a calc-alkaline dacite composition. Total thickness of the Tisdale Group is about 4000 m.
>
> "Metasediments, consisting dominantly of interlayered wacke, siltstone and lesser conglomerate form part of what is mainly a turbidite sequence, the lower portion of which is time equivalent to the upper portion of the Deloro Group and the entirety of the Tisdale Group. This turbidite sequence, together with a thin sequence of overlying fluviatile sediments is termed the Porcupine Group. Total exposed thickness of the group is approximately 3000 m.

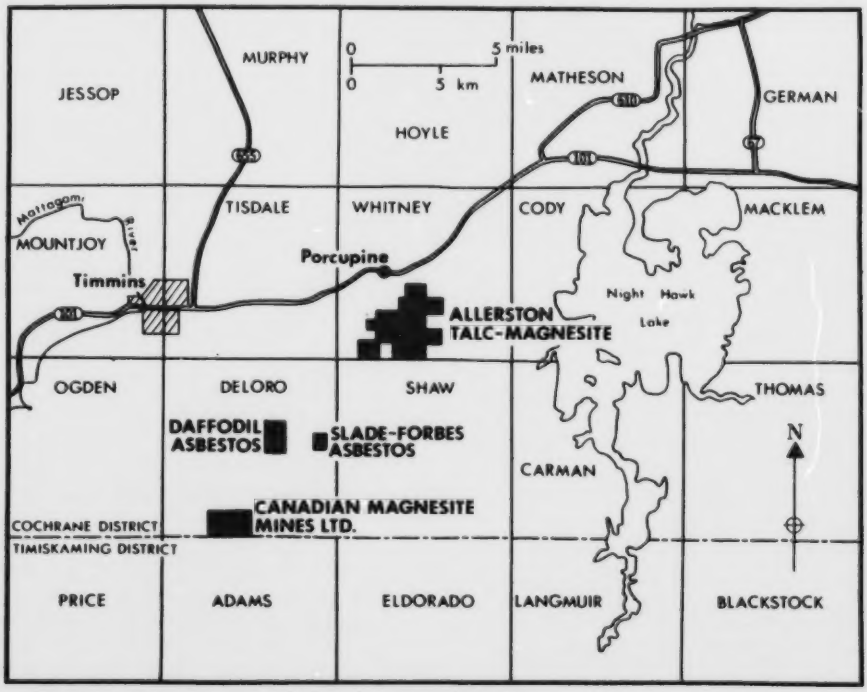


Figure 2. *Location map of Timmins area deposits.*

"Large, generally sill-like bodies of medium- to coarse-grained dunite and lherzolite were emplaced almost entirely within the Deloro Group of metavolcanics. Some of the sills are interpreted to have provided a magma source for some of the overlying ultramafic metavolcanics of the Tisdale Group.

"Minor, small epizonal quartz-feldspar porphyry intrusions, probably of subvolcanic origin, were intruded into the metavolcanics. Most of these intrusions occur in a restricted stratigraphic interval, suggesting that they may in part represent extrusive rhyolitic domes.

"A major structural break, the Destor-Porcupine Fault, trends northeast across the northern part of the area. North of the fault, two periods of folding can be discerned; an original north-trending series of folds were subsequently refolded about an east-northeast axis. South of the Destor-Porcupine Fault, the Shaw Dome forms the main structural feature; the axis trends about east-west across the southern part of Shaw Township."

STRATIGRAPHIC POSITION OF TALC, MAGNESITE AND ASBESTOS DEPOSITS

A generalized stratigraphic and structural interpretation of the Timmins area, from Pyke (1980), is presented in Figure 3. It shows the location of the four deposits studied.

The Canadian Magnesite Mines deposit occurs in Formation IV, the lower volcanic formation of the Tisdale Group. This formation consists predominantly of peridotitic and basaltic komatiites at the base, and interlayered komatiites and Mg-tholeiite in the upper portion (Pyke 1980, p.124).

The Allerston talc-magnesite deposit occurs in the upper volcanic Formation III of the Deloro Group, which is characterized by abundant iron formation. Calc-alkalic rhyolitic and dacitic tuff and lapilli-tuff form the bulk of the formation (Pyke 1980, p.123).

Both the Daffodil asbestos deposit and the Slade-Forbes asbestos deposit are in Formation II, the middle volcanic formation of the Deloro Group. Formation II is composed almost entirely of flows of calc-alkalic basalt and andesite, and it is only near the upper part of the formation that pyroclastic rocks predominate. Most ultramafic rocks are confined to this formation (Pyke 1980, p.123).

In summary, in a regional context, it seems that talc, magnesite and asbestos deposits can occur wherever ultramafic rocks occur and that in the Timmins area, these are not stratigraphically restricted.

CANADIAN MAGNESITE MINES MAGNESITE–TALC DEPOSIT, DELORO TOWNSHIP

In 1959, A.T. Griffis recognized that an extensive talc-carbonate zone in Deloro Township was, in fact, a magnesite-talc altered ultramafic rock. Carbonate zones had been described as early as 1944 (Longley 1944) and the gold potential of the carbonate zones was considered to be high. In 1962, the property (Figure 4) was acquired by Canadian Magnesite Mines Limited. Since then, considerable work consisting of industrial testing, geological mapping and chemical analyses has been carried out by Canadian Magnesite Mines Limited with a view to recovering magnesite and/or talc. The published work on this deposit consists of papers by Svikis (1968), R.J. Griffis (1970, 1972), Industrial Minerals (April, 1971, p.40-43), and A.T. Griffis (in press). Our work entailed remapping and sampling the main magnesite-talc body and environs. Chemical analyses of whole-rock samples and electron microprobe analyses of carbonate and opaques were done and thin sections have been described. The carbon and oxygen isotopic compositions of four highly carbonate-altered komatiitic dunites were determined and the results are discussed below under "Geochemistry and Alteration Processes".

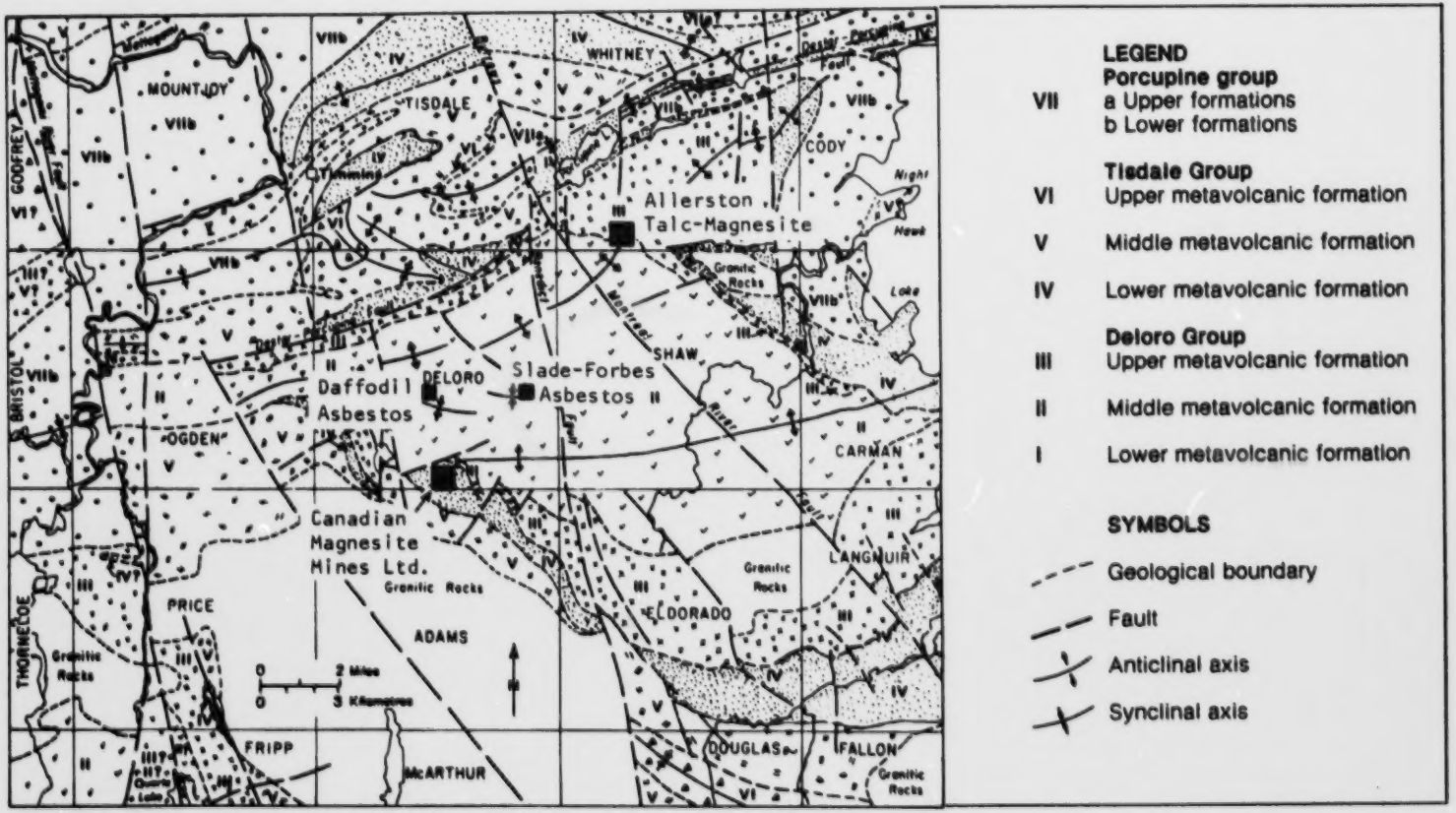


Figure 3. *Distribution of stratigraphic units in Timmins area and location of deposits.*

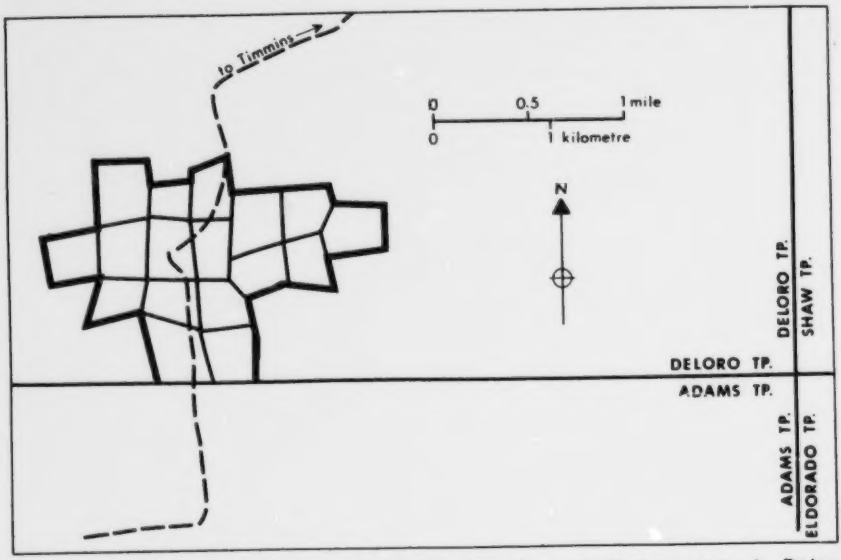


Figure 4. *Claim map of Canadian Magnesite Mines Limited property in Deloro Township.*

ECONOMIC GEOLOGY

The deposit consists of either a single large magnesite-talc altered dunitic komatiite or a series of altered flows (Figure 5, Chart A, back pocket, and Figure 6). It is hosted by basaltic or andesitic lavas, serpentinized peridotitic komatiite and quartz-carbonate iron formation. It is about 1800 m long, has a maximum width of 300 m and has been drilled to a depth of 120 m (Figure 6). About 100 million tonnes are drill-indicated, grading 50 percent magnesite and 25-30 percent talc (Industrial Minerals, April 1971). More than $1 million has been spent on the property since 1962.

The very low CaO content in the magnesite-talc body makes the carbonate mineralization a potential source of refractory magnesia. However, iron substitution in the magnesite lattice (discussed under "Mineralogy and Chemistry") means that the iron cannot be removed by standard physical methods. The iron, therefore, limits the grade of magnesia concentrate or dead-burned refractory product. Extensive metallurgical testing by Canadian Magnesite Mines over a period of years has demonstrated that the best grade of magnesite obtained by flotation concentration produces a 92-94 percent dead-burned MgO product with 4-6 percent Fe_2O_3. A typical analysis (Industrial Minerals, April 1971, p.43) of dead-burned MgO product is given as:

MgO	92.5 percent
Fe_2O_3	6.0-6.5 percent
SiO_2	1.0 percent
CaO	less than 0.2 percent
miscellaneous	less than 0.5 percent
boron	10 ppm

(bulk density is 3.45 to 3.47 at dead-burning temperature of 1650°C)

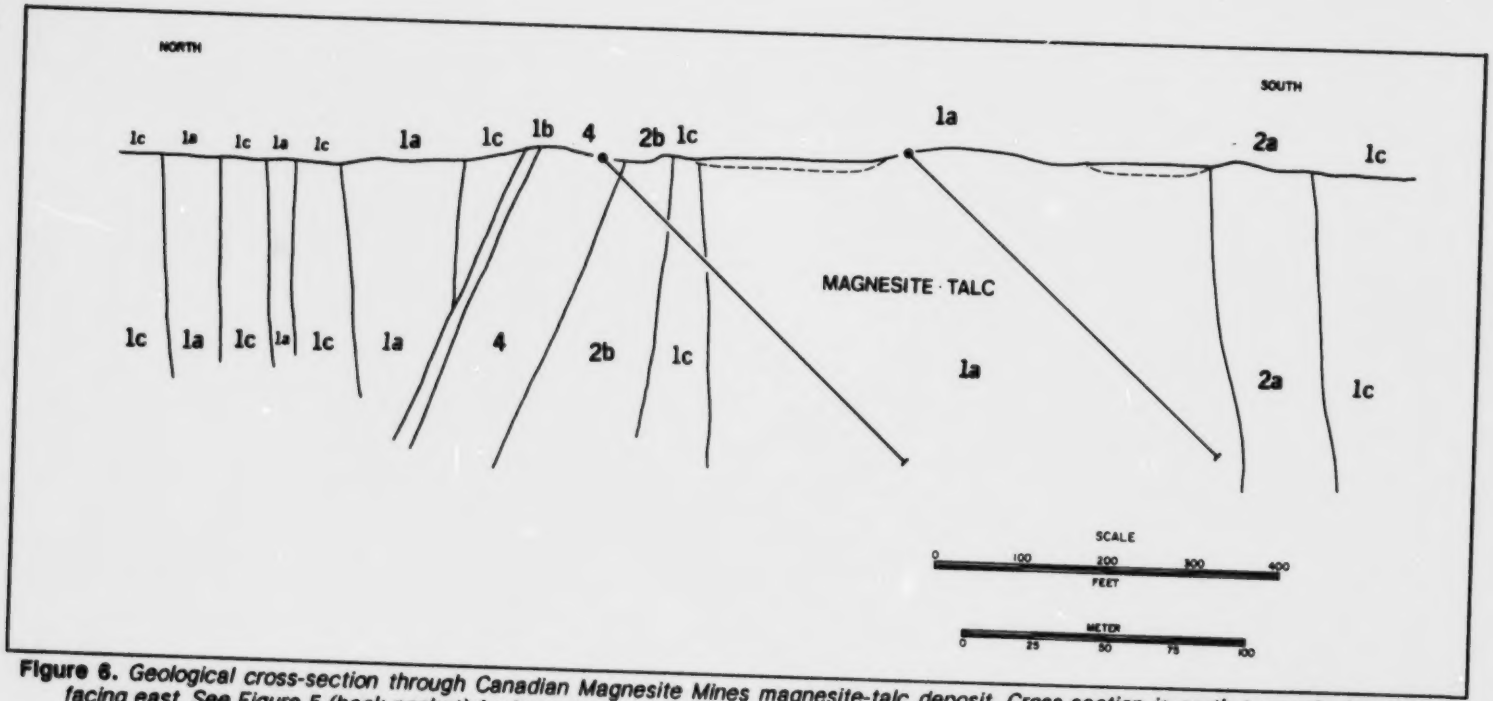

NORTH
SOUTH
1c 1a 1c 1a 1c 1a 1c 1b 4 2b 1c 1a 2a 1c
MAGNESITE · TALC
1c 1a 1c 1a 1c 1a 4 2b 1c 1a 2a 1c
SCALE
0 100 200 300 400
FEET
METER
0 25 50 75 100

Figure 6. *Geological cross-section through Canadian Magnesite Mines magnesite-talc deposit. Cross-section is north to south through pit, facing east. See Figure 5 (back pocket) for legend.*

By-product talc also produced by flotation is given as (Industrial Minerals, April 1971, p.43):

total MgO	31.61 percent
SiO_2	62.24 percent
total Fe*	0.35 percent
L.O.I.	5.27 percent
CaO	nil
Al_2O_3	nil

*total Fe as Fe_2O_3

The MgO product from Canadian Magnesite Mines Limited's deposit cannot compete with higher purity magnesia recovered from seawater operations. More recently, several chemical methods of making high-purity magnesia from the Canadian Magnesite Mines deposit have been investigated, but as yet have not proved to be economical (A.T. Griffis, in press).

No other information is available regarding the quality of the talc from the Canadian Magnesite Mines body.

GEOLOGY

The main magnesite deposit is either a large carbonate-altered dunitic komatiite body or a series of dunitic or peridotitic komatiite flows (Figures 5 and 6). It cannot be determined with certainty whether it is one or the other because of the extensive alteration. Two lenses of magnesite-talc rock strike northeast and dip steeply to the north. The cross-section (Figure 6) is from Canadian Magnesite Mines Limited's files and is based on extensive drilling. A northeast-trending (block?) fault mapped by Canadian Magnesite Mines which apparently displaces the eastern portion of the ore zone slightly has been omitted for clarity on Figure 5 (Chart A, back pocket). Poorly preserved spinifex textures and the fact that the ultramafic sequence occurs on the southwest flank of the Shaw Dome indicate that tops are probably to the south. The quartz-carbonate iron formation therefore overlies the altered flows.

Intensely altered dunitic komatiite and peridotitic komatiite have very similar field characteristics. The weathered surface is generally brown to greyish brown (e.g. samples 2102, 2108 and vicinity) and has a patchy appearance. On fresh surface, they are grey, very soft, talcose and generally non-magnetic. Samples fizz in dilute HCl. A reddish colour due to a fine dusting of disseminated hematite and rutile is common. Magnetite is a minor constituent throughout the highly altered zone but increases near the contact with less altered volcanic rocks. This gives rise to a subtle concentric compositional zoning of the main magnesite body. Locally, green mica (fuchsite?) flakes and rusty-weathering pyrite are seen. Quartz veins are very abundant and may constitute up to 30-40 volume percent in some locations (Photo 1) They reflect the intensive carbonate alteration and accompanying release of silica.

Near the southern boundary of the main magnesite zone, quartz veins contain hematite and rutile and both quartz veins and disseminated hematite and rutile seem to be more abundant than at the north boundary. Sample 2111 is white to light grey on fresh surface, is slightly foliated and in general closely resembles marble.

Carbonate alteration is so intense that only vague evidence of the original spinifex textures remains. This consists of repeated talc or chlorite-carbonate zones parallel to the major contacts. Occasionally, talc and chlorite blades radiate in a manner similar to original olivine spinifex blades. The spacing and overall geometry of the chlorite zones also suggests they were originally spinifex.

Massive peridotitic komatiite flows in the southwest corner of the property are unaltered or are less altered (to carbonate). They are light to dark green or bluish green on fresh surface and also weather brown. They are moderately to strongly magnetic and do not fizz in dilute HCl. Other, more detailed field characteristics of these types of komatiites were presented by Arndt *et al.* (1979).

Photo 1. *Extensive quartz veining accompanying complete carbonate alteration of dunitic komatiitic flows at Canadian Magnesite Mines deposit. Location near sample 2103.*

Spinifex-bearing and massive polyhedrally-jointed komatiites at the east end of the property are interbedded with siliceous iron formation and are strongly carbonated. They represent a separate, thinner, magnesite-talc zone.

Basaltic komatiite is massive, dense and dark green in colour. No clinopyroxene spinifex was seen, but fragments of brecciated flow tops and vague pillow shapes outcrop.

At the east end of the property, "iron formation" is almost pure quartzite which in places has recrystallized to quartz veins that cross-cut bedding. Locally iron formation displays beds of jasper or reddish-coloured volcanic fragments and carbonate. At the west end of the property, on the other hand, the "iron formation" is a thin carbonaceous pyritic tuff. Pyrite occurs as concentrically zoned balls. In one place the carbonaceous unit directly overlies the carbonated komatiitic flows and in another, there is thin (several metres thick) argillaceous tuff interposed.

The host volcanic rocks that overly the magnesite-talc zone are massive andesite, andesite breccia and minor dacite and quartz-crystal lapilli-tuff. Locally, units are highly carbonate-altered, e.g. sample 2136, which is creamy white to yellowish and fizzes in dilute HCl. This unit overlies the argillaceous tuff. The underlying basalt is massive and dark green in colour and displays vague outlines of pillows (e.g. samples 2121, 2143).

The evidence from field and textural relationships is that carbonate alteration is stratigraphically and also probably compositionally controlled. Alteration of dunitic komatiite or the MgO-rich basal portions of peridotitic spinifex-bearing flows is most intense, while host peridotitic komatiite and intermediate volcanic rocks are less carbonated. Field relations thus suggest that alteration is a primary feature which is in some way related to the original carbonate content of either the sea floor on which the komatiite was extruded or the seawater into which it was extruded.

MINERALOGY AND CHEMISTRY

Mineralogic and chemical variations in the Canadian Magnesite Mines Limited magnesite-talc body have been studied by R.J. Griffis (1970). Results are published in Griffis (1972). Our work confirms much of Griffis' work and extends his field and petrographic observations to include the komatiitic nature of the ultramafics. Eighteen whole-rock chemical analyses and petrographic descriptions are presented in Tables 1 and 2. These analyses are plotted on the Jensen cation plot (Jensen 1976), Figure 7, and clearly demonstrate the komatiitic affinity of the magnesite-talc rocks. Microprobe analyses of oxides (opaque minerals) and carbonate are presented in Tables 3 and 4. The trace element concentrations in overlying iron formation are presented in Table 5. The mineralogy of the four most common rock types on the property is given in Table 6 (Griffis 1972).

Because of chemical heterogeneity of individual komatiitic flows and their differences in susceptibility to carbonate alteration, the correlation between Griffis' rock types and our field classification (see Figure 5) is not entirely consistent. In general, Griffis' rock types I and II represent highly altered dunitic komatiite (1a on Figure 5, e.g. samples 2100 to 2104 are Type I; 2111 is Type II). Type II is more highly altered than Type I. Rock type III corresponds to a dunitic komatiitic that was not completely carbonated or a peridotitic komatiite that was less susceptible to carbonate alteration (e.g. sample 2108). Type IV corresponds to map-unit 1b on Figure 5.

In thin sections, the most common rock, Type I, has a patchwork fabric which is dominated by medium-sized magnesite grains with finer interstitial aggregates of talc and quartz. According to Griffis (1972, p.64) textural relations between magnesite, talc and quartz are ambiguous. Magnesite may replace talc and vice versa. Also, while two stages of quartz formation are indicated, textural relations cannot be used to quantify the replacement of or by silica.

A second type of magnesite-bearing rock (Type II) is exposed in one small outcrop near the east end of the main magnesite zone (sample location 2111). The fabric of this rock shows interlocking carbonate grains, but textural relations cannot be used to define a paragenetic sequence. Quartz and carbonate seem to exist in equilibrium and magnesite has replaced most of the talc.

The third type of carbonate rock (Type III) contains magnesite, talc and serpentine in varying proportions. Minor amounts of hematite and magnetite are also present. In most samples, the magnesite content approximates 49 percent while talc and serpentine vary considerably. The rock commonly has a granular texture and small irregular veinlets of carbonate are frequently seen. No quartz was observed in any samples of this rock type.

Rock type IV represents incipient carbonate alteration of dunitic or peridotitic komatiite. No original ferromagnesian minerals remain but serpentine pseudomorphs olivine. Magnesite and oxides are concentrated along grain boundaries.

The CaO content of all magnesites analysed was less than 0.18 weight percent.

The composition of carbonate in the carbonate-altered calc-alkalic dacite overlying the magnesite body (sample 2136) is that of an iron-bearing dolomite (Table 4).

Table 5 shows the trace element concentration in the iron formation directly overlying highly altered dunitic komatiite in the southwest corner of the property (Figure 5). Ni, Cr and TiO_2 concentrations might be expected to be elevated if these constituents are lost from the sequence of komatiitic flows during carbonate alteration. No major concentration of Ni or Cr has taken place. TiO_2 concentration on the other hand, is slightly raised. These observations bear on the alteration process and are discussed separately.

Microprobe analyses and polished sections from four locations (Tables 3, 4) show that in the central area where the most highly carbonated dunite outcrops (locations 2103, 2104, 2115) hematite and rutile are the major oxides. These

TABLE 1. CHEMICAL ANALYSES AND NORMATIVE COMPOSITIONS OF WHOLE-ROCK SAMPLES FROM CANADIAN MAGNESITE MINES DEPOSIT.

Anal. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Samp. No.	2100	2102	2108	2111	2131	2133	2136	2137	2139	2140	2141	2143	2144	2145	2147	2149	2151	2152
Major Elements																		
SiO_2	27.65	30.36	29.85	30.26	41.62	35.40	56.87	34.38	63.42	24.17	36.47	61.36	40.11	37.00	32.63	33.41	48.32	53.90
TiO_2	0.04	0.03	0.02	0.01	0.52	0.30	0.71	0.30	0.60	0.21	0.23	0.78	0.46	0.01	0.00	0.22	0.78	0.10
Al_2O_3	1.90	0.05	0.27	0.18	8.58	5.24	15.40	6.34	13.84	4.29	5.17	14.46	6.54	0.36	0.00	3.98	14.19	2.42
Fe_2O_3	5.37	5.60	5.04	4.19	0.72	0.65	0.28	0.39	0.79	0.00	0.00	1.19	1.32	5.52	0.80	1.20	1.84	1.09
FeO	n.d.	n.d.	n.d.	n.d.	7.70	6.83	2.46	6.30	4.71	6.64	7.10	6.37	7.56	2.99	3.78	5.71	10.15	4.65
MnO	0.05	0.05	0.06	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MgO	34.16	35.52	36.84	29.83	10.51	14.99	2.68	7.97	2.02	10.54	13.37	3.61	13.72	36.32	39.66	16.84	5.00	27.73
CaO	0.06	0.04	0.11	0.09	10.01	12.39	5.48	16.30	2.63	20.89	13.76	2.19	10.66	0.92	0.25	13.18	6.35	2.32
Na_2O	n.d.	n.d.	n.d.	n.d.	2.12	0.21	4.51	0.34	6.55	2.19	0.31	5.30	0.11	0.00	0.00	0.93	3.18	0.00
K_2O	0.01	0.00	0.00	0.00	0.00	0.00	2.55	2.00	0.18	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00
P_2O_5	0.00	0.01	0.02	0.00	0.07	0.06	0.34	0.04	0.18	0.06	0.05	0.23	0.06	0.03	0.06	0.06	0.09	0.05
$H_2O_{tot.}$	0.96	1.13	1.69	0.01	3.07	3.25	0.87	0.64	1.32	0.28	3.03	2.70	4.08	10.98	8.81	2.16	4.05	4.14
CO_2	29.36	28.62	25.40	35.03	15.22	20.86	7.42	24.91	3.30	31.04	20.65	1.32	15.42	5.53	11.12	21.92	4.87	3.50
TOTAL	99.56	101.41	99.29	99.65	100.14	100.18	99.57	99.91	99.54	100.36	100.14	99.51	99.98	99.66	100.11	99.61	99.52	99.90
Trace Elements																		
S	n.d.	n.d.	n.d.	n.d.	0.05	0.10	0.06	0.22	0.02	0.12	0.01	0.00	0.01	0.12	0.02	0.10	0.03	0.01
Ni	3222	3300	3222	2515	232	1202	73	1446	42	796	669	75	730	2865	2791	1071	124	2200
Cr	820	680	615	615	786	1847	82	2018	82	1669	1402	136	1956	1402	1231	1587	82	3817
Normative Minerals																		
Q	0.00	0.00	0.00	0.00	0.00	0.00	7.70	0.00	14.90	3.80	0.00	17.60	0.00	0.00	0.00	0.00	1.10	5.80
Or	0.10	0.00	0.00	0.00	0.00	0.00	16.50	0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.60	0.00
Ab	0.00	0.00	0.00	0.00	21.90	0.00	41.80	0.00	58.40	0.00	0.00	47.00	1.20	0.00	0.00	0.00	29.70	0.00
An	0.40	0.20	0.60	0.70	17.00	17.60	15.60	13.30	8.30	2.30	16.60	9.80	21.50	1.20	0.00	8.90	24.70	7.20
Opx	4.20	12.20	5.50	37.20	5.00	0.00	6.20	0.00	10.90	0.00	0.00	19.30	33.80	24.60	6.10	0.00	27.30	81.10
Cpx	0.00	0.00	0.00	0.00	34.90	50.00	9.40	42.10	3.60	0.00	56.30	0.00	35.00	3.20	0.80	38.00	7.80	3.90
Ol	89.20	83.80	90.60	58.60	18.60	28.90	0.00	15.00	0.00	36.90	23.80	0.00	4.90	68.20	91.40	35.30	0.00	0.00
Ne	0.00	0.00	0.00	0.00	0.00	1.30	0.00	2.10	0.00	13.40	1.90	0.00	0.00	0.00	0.00	5.60	0.00	0.00
Lar	0.00	0.00	0.00	0.00	0.00	0.10	0.00	13.40	0.00	40.50	0.70	0.00	0.00	0.00	0.00	9.10	0.00	0.00
Cor	2.60	0.60	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	0.00	0.00	0.00	0.00	0.00	0.00
Il	0.10	0.10	0.10	0.00	1.20	0.70	1.50	0.80	1.20	0.50	0.60	1.60	1.10	0.00	0.00	0.60	1.60	0.20
Mt	3.20	3.10	3.10	3.40	1.30	1.20	0.40	0.80	1.20	0.00	0.00	1.80	2.40	2.60	1.50	2.30	2.90	1.70

TABLE 1. Continued

NOTES
n.d. - not determined;
Oxides and S expressed in weight percent. Trace elements in ppm.
Analyses 1-4, method: XRF; analyst: M. Gorton, University of Toronto.
Analyses 5-18, method: standard wet chemical; analyst: V. Kubat, Ecole Polytechnique, Montreal.
Norms are CIPW.

Analysis No.	Field Name	Jensen Plot Classification	Griffis(1972) Rock Type
1.	carbonate-altered peridotitic komatiite	peridotitic komatiite	I
2.	carbonate-altered peridotitic komatiite	peridotitic komatiite	I
3.	carbonate-altered peridotitic komatiite	peridotitic komatiite	III
4.	white magnesite rock	peridotitic komatiite	II
5.	talc-chlorite rock	basaltic komatiite	
6.	chloritic, siliceous rock	altered	
7.	carbonate-altered volcanic rock	calc-alkalic dacite	
8.	altered intermediate volcanic rock	altered, 12.5% normative Lc	
9.	argillaceous, pyritic tuff	calc-alkalic andesite	
10.	carbonate-altered dunite	altered, 2.1% normative Wo	I
11.	carbonate-altered spinifex	altered	II
12.	fragmental basalt	calc-alkalic basalt	
13.	altered spinifex	basaltic komatiite	I
14.	peridotitic komatiite	basaltic komatiite	
15.	peridotitic komatiite	peridotitic komatiite	II
16.	carbonate-altered spinifex	altered	II
17.	basalt	tholeiitic basalt	IV
18.	carbonate-altered spinifex with talc	peridotitic komatiite	II

TABLE 2. MODAL ANALYSES (VOLUME PERCENT) OF WHOLE ROCK SAMPLES FROM CANADIAN MAGNESITE MINES DEPOSIT.

Analysis No. / Sample No.	1 2100	2 2102	3 2108	4 2111	6 2133	8 2137	9 2139	10 2140	11 2141	12 2143	14 2145	15 2147	16 2149	17 2151	18 2152
Carbonate	50	70	80	64	65	80	10	75	75	3	48	70	65	5	80
Quartz	10	5		25	30	5	10	20	15	50			25	5	10
Talc	25	20	15	10						2		30	5		10
Chlorite	13					12		3	10	25				75	
Oxides	2	5	5	1		3		2			4		2	5	
Serpentine					5		80				48				
Antigorite										20			3	5	

Notes
1. For sample descriptions, see Table 1.
2. Modes were not calculated for samples 2131, 2136, and 2144.

TABLE 3. MICROPROBE ANALYSES[1] OF OPAQUES IN SAMPLES FROM CANADIAN MAGNESITE MINES DEPOSIT.

Analysis No.	21	24	27	12	13	14	15	16	17	18	33	34
Sample No.	2103	2103	2103	2104	2104	2104	2104	2104	2104	2104	2123	2123
Al_2O_3							0.31				14.38	12.08
TiO_2		0.49				0.35	0.48				0.21	0.21
Cr_2O_3	0.20	0.20	1.77	3.00	3.40	1.93	3.29	2.08	0.20	0.21	46.66	40.78
FeO											8.94[4]	11.36[4]
Fe_2O_3	98.67[2]	97.38[2]	97.11[3]	94.69	93.37	95.81	94.87	95.43	98.12	99.10	22.06	28.06
MgO		0.41									6.52	1.54
Sum	98.87	98.48	98.88	97.69	96.77	98.09	98.95	97.51	98.73	99.31	98.77	96.20
Oxide Mineral[3]	hm	hm	hm	hm	hm	hm	hm	hm	hm	hm	cr	cr

NOTES
1. Analyst: C. Cermignani, University of Toronto. See Appendix A.
2. Reported as FeO.
3. hm = hematite, cr = chromite.
4. Iron was analysed as FeO and proportioned between Fe^{+2} and Fe^{+3} assuming stoichiometric spinel and assuming TiO_2 substitutes as ulvospinel.

TABLE 4. MICROPROBE ANALYSES OF CARBONATE IN MAGNESITE AND OTHER SAMPLES FROM CANADIAN MAGNESITE MINES DEPOSIT.

SAMPLE 2103

Grain 1
15 points analysed[1]
FeO content: 1.28 ± 0.35 wt. %[2]
Range 1.01 to 1.88 wt. %

Grain 2
5 points analysed
FeO content: 2.41 ± 0.66 wt. %
Range: 1.74 to 3.48 wt. %
CaO (one analysis) 0.11 wt. %

Grain 3
10 points analysed
FeO content: 3.6 ± 2.3 wt. %
Range 1.89 to 7.93 wt. %
MnO (one analysis) 0.11 wt. %

Grain 4
7 points analysed
FeO content: 2.3 ± 1.9 wt. %
Range: 0.82 to 6.50 wt. %

SAMPLE 2104[3]

Grain 1
10 points analysed
FeO content: 1.00 ± 0.57 wt. %
Range: 0.21 to 1.52 wt. %

Grain 2	R[4]	C	R
FeO	1.40	1.37	1.06
MgO	48.72	48.48	54.60
Sum	50.12	49.85	55.66

Grain 3	R[4]	C	R
FeO	1.39	1.52	1.29
MgO	48.59	48.15	48.30
Sum	49.98	49.67	49.59

SAMPLE 2115[5]

Grain 1	R	C	R
FeO	11.79	11.67	11.61
MgO	40.79	40.63	41.18
CaO			0.10
Sum	52.58	52.30	52.89
Grain 2			
FeO	6.97	17.24	8.53
MgO	43.65	36.38	43.42
CaO			0.10
Sum	50.62	53.62	52.05
Grain 3			
FeO	9.06	8.00	10.20
MgO	42.53	43.16	41.82
CaO		0.18	
MnO			0.15
Sum	51.59	51.34	52.17

SAMPLE 2130

Average Composition of 4 Analyses

	Wt. %	Mol. %
FeO	3.5	2.0
MgO	47.1	48.0
CaO	0.0	0.0

SAMPLE 2136

FeO	12.8	8.7
MgO	12.9	15.8
CaO	28.5	24.9

Sample Descriptions
2103, 2104, 2115: magnesite
2130: quartz-carbonate vein with disseminated rutile and hematite
2136: carbonate altered calc-alkalic dacite

NOTES
1. Analysts: C. Cermignani and A. Robinson, University of Toronto.
2. From counting statistics, relative standard deviation is: MgO ± 2.0%, FeO ± 0.4%.
3. Carbonates in 2104 luminesce blue, those in 2115 do not.
4. R = rim, C = center.
5. Note: in sample 2115, rutile is the major oxide.

TABLE 5. TRACE ELEMENT CONCENTRATIONS (ppm) IN IRON FORMATION SAMPLES FROM CANADIAN MAGNESITE MINES DEPOSIT.

Sample No.	Ni	Cr	TiO_2	Cu	Pb	Zn	Ag
2134	430	670	0.40%	44	1	760	1.0
2135	1	38	0.52%	36	2	90	0.1
2142B	30	100	0.34%	6	32	18	2.2

Sample Description
2134: argillaceous tuff
2135: graphitic pyritic tuff
2142B: graphitic pyritic tuff

Analyst: Hart Bickle, Chemex Labs Ltd., Vancouver.

TABLE 6. MINERALOGY OF THE FOUR MOST COMMON ROCK TYPES IN CANADIAN MAGNESITE MINES DEPOSIT (after Griffis 1972).

	Type I	Type II	Type III	Type IV
magnesite	54 ± 3%	70 ± 3	about 40%	serpentinized dunite or peridotite
talc	28 ± 3	16 ± 3	very variable	
serpentine	–	–		
quartz	16 ± 2	8 ± 2	–	
opaques	3	1	minor	
mole % $MgCO_3$ in magnesite	89	92		
mole % $FeCO_3$ in magnesite	11	8	2-4	

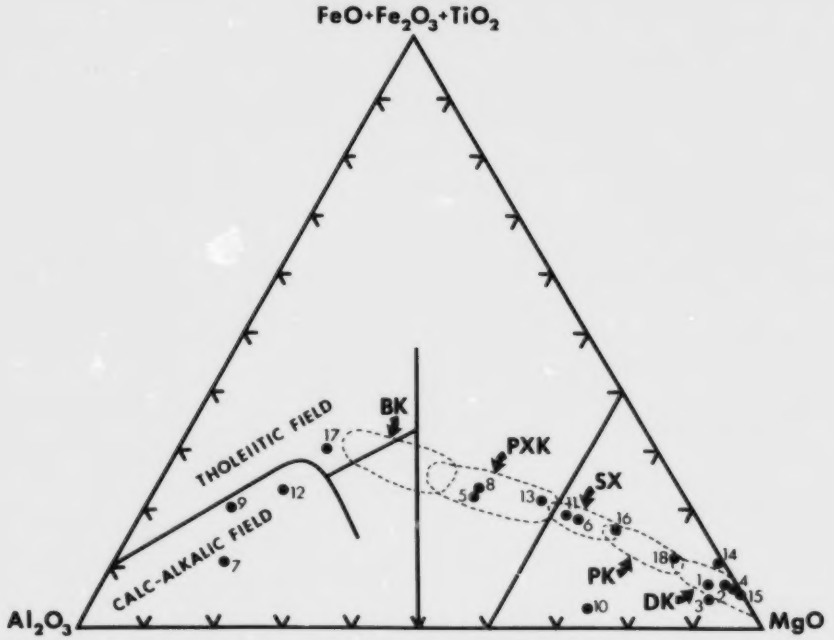


Figure 7. *Jensen cation plot of chemical analyses of whole-rock samples from Canadian Magnesite Mines deposit. Subdivision of komatiite types is generalized from Arndt (1975), Naldrett and Turner (1977), Arndt et al. (1977), and Nesbitt et al. (1979). Compositional ranges overlap but are approximately as follows (percent MgO, anhydrous): DK, dunitic komatiite, more than 40 percent MgO; PK, peridotitic komatiite, 30-40 percent MgO; SX, olivine spinifex, 20-30 percent MgO; PXK, pyroxenitic komatiite, 12-20 percent MgO; BK, basaltic komatiite, less than 12 percent MgO.*

generally occur as minute grains uniformly disseminated in magnesite or along magnesite-talc grain boundaries. Locally there are thin layers of hematite and rutile that roughly parallel major contacts. Magnetite occurs only in less carbonated and less magnesian samples (e.g. 2131).

Chromites from the host peridotitic komatiite to the southwest (sample 2123, Figure 5) have compositions similar to those described for cumulate zone peridotitic komatiite (Arndt *et al.* 1977). The chromites are subhedral and are rimmed with magnetite that was liberated during serpentinization.

Microprobe analyses of carbonate from locations 2103, 2104, 2130 (Table 4), show that some iron occurs as solid solution in magnesite. Individual grains may be zoned or may display an inhomogeneous $FeCO_3$ distribution (e.g. 2104) between the rim (R) and centre (C) of grains. More importantly, iron in solid solution varies from about 1 to 21 molecular percent $FeCO_3$ between grains from the same location (Table 4). The maximum iron content observed is slightly higher than that determined by R.J. Griffis (1972) but overall, the range of $FeCO_3$ determined by microprobe is generally similar to that determined by Griffis (1972) by wet chemical analysis, namely 8 to 11 molecular percent $FeCO_3$ in $MgCO_3$.

The average composition of four relatively homogeneous carbonate grains from a quartz, magnesite, hematite and rutile vein (location 2130) is 2 molecular percent $FeCO_3$ in $MgCO_3$, significantly less than the carbonated dunite host.

DISCUSSION

1. The magnesite-talc rocks that constitute the magnesite deposit of Canadian Magnesite Mines Limited have a clear komatiitic affinity and represent completely carbonated komatiites. This komatiitic affinity and that of the enclosing host rock is demonstrated by chemical and petrographic criteria (e.g. Figure 7).

2. Magnesite content is a function of several variables:

a) Original bulk composition of the komatiitic flow. Altered dunitic komatiite and peridotitic komatiite have higher magnesite contents than pyroxenitic or basaltic komatiites.

b) Degree of carbonate alteration. More magnesian komatiites alter more readily than less magnesian komatiites.

c) Physical factors. Spinifex-bearing komatiite with its more open network structure of olivine or pyroxene crystals seems to be more susceptible to carbonate alteration than massive cumulate komatiite which may have a higher MgO content.

3. Iron in magnesite in the deposit occurs predominantly as finely disseminated hematite and as $FeCO_3$ in solid solution. The chances of obtaining iron-free MgO for metallurgical applications from magnesite derived from such Archean komatiites seem to be slim. Physical separation of iron-bearing phases is not possible, and expensive and technologically complicated techniques must be used. This, in fact, has stalled the exploitation of this deposit, as has been pointed out above.

4. The high quartz content in the magnesite-talc deposit results in a talc product with a high wire loss on abrasion tests and therefore with a limited range of applications.

ALLERSTON TALC–MAGNESITE DEPOSIT, WHITNEY TOWNSHIP

The Allerston talc-magnesite deposit in Whitney Township (see Figures 1 and 2) was staked by Ralph Allerston in 1964. In 1975 the property (Figure 8) was optioned by Rosario Resources Canada Limited who subsequently carried out extensive trenching, stripping, bulk sampling, detailed geological mapping and geophysical surveys. In addition, 16 diamond drill holes totalling 930 m were drilled. The results of the exploration work by Rosario Resources are contained in a voluminous unpublished report on the property by Bowen *et al.* (1976) and much of the following information is taken from that report. Our work consisted of field checks of the geological mapping, collecting bulk samples of talc-magnesite rock for three new whole-rock chemical analyses and examination of thin sections. The thin sections were provided by Bob Middleton, formerly of Rosario Resources Canada Limited.

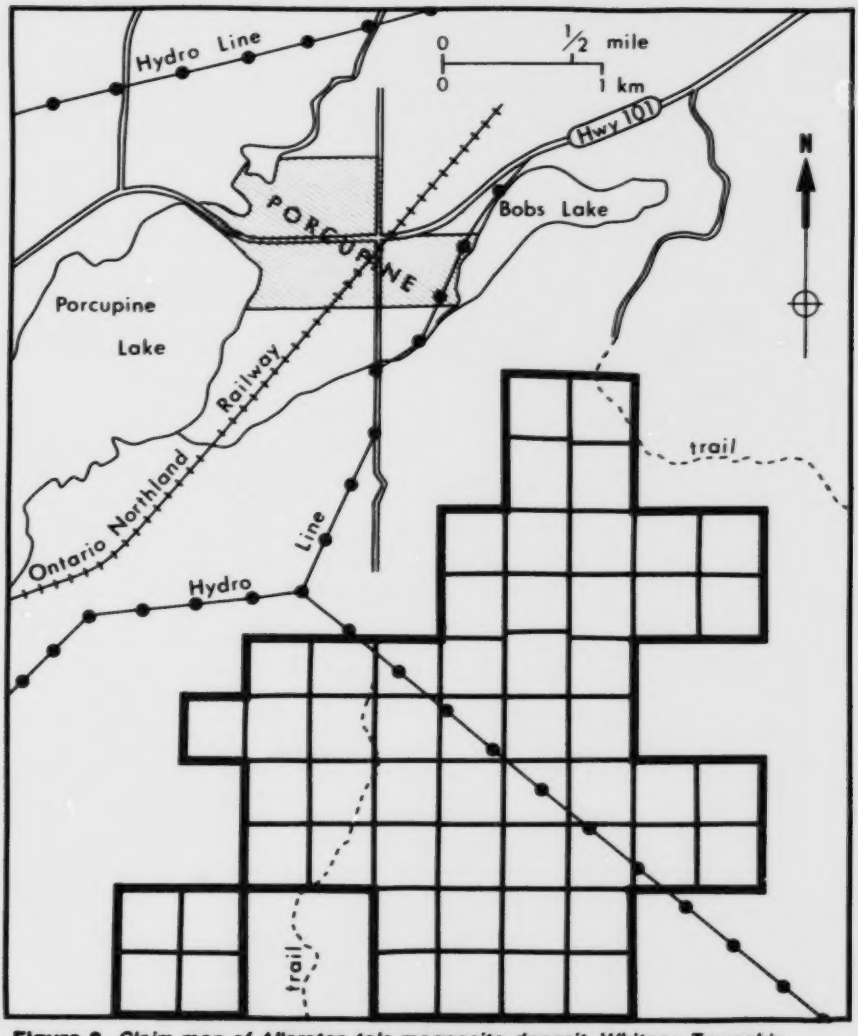


Figure 8. *Claim map of Allerston talc-magnesite deposit, Whitney Township.*

ECONOMIC GEOLOGY

There are two areas of talc-magnesite, a north and a south zone, (Figure 9, Chart A, back pocket). Diamond drilling by Rosario Resources Canada Limited and Oro Mines Limited showed these to be approximately 30 m thick, (Figure 10). The area of outcropping talc-magnesite ore is 40,900 m^2 for the North Zone and 7,400 m^2 for the South Zone. Assuming a tonnage factor of about 1.37 tonnes/m^3 (175.5 pounds per cubic foot) to a depth of 30 m, that the outcrops are continuous, and that the South Zone cross-section (Figure 10) is correct, conservative tonnage estimates are 6.3 million tonnes for the North Zone and 28.7 million tonnes for the South Zone. In addition, in the North Zone area, an outcrop area of about 137,000 m^2 of peridotite is probably underlain by talc-magnesite, which gives another possible 1.8 million tonnes. A conservative estimate for the property is therefore 36.8 million tonnes. Details of this estimate are provided by Bowen *et al.* (1976).

The results of metallurgical tests carried out by Rosario Resources have not been published. It is however known that economically viable talc concentrate can be obtained. The property is currently held jointly by Rosario Resources Canada Limited and Steetley Talc Limited.

GEOLOGY

A geological map of the property, based on the work of Bowen *et al.* (1976), is shown as Figure 9, which also shows the location of samples (both Rosario Resources' and those collected for this report) and diamond drill holes from which chemical analyses are available.

The talc-magnesite altered komatiites that constitute the Allerston deposit occur in the upper part of the Deloro Group in felsic and intermediate tuffs and cherty sulphide iron formation (Pyke 1980).

There are two zones of talc-magnesite mineralization, the North and South Zones. The North Zone is overlain by peridotite and is underlain by peridotite and/or intrusive feldspar porphyritic aplite. The South Zone is overlain by andesitic tuff, chert and intermediate tuff and is underlain by chlorite-carbonate schist (peridotitic komatiite) and magnetite-jasper iron formation.

The strata are relatively flat lying and this together with poor exposure make it difficult to determine stratigraphy precisely.

Volcanic Rocks (Unit 1)

Mafic units occur as flows, tuff, lapilli-tuff, agglomerate and narrow sills. The rocks are calc-alkalic basalt or andesite (see Figure 11). All are chloritized and some are carbonate-altered. The flows are fine grained (less than 1 mm). The weathered surfaces are light greenish grey to brown. Fresh surfaces are lighter in colour. Phenocrysts of carbonate and occasionally quartz are present, as are stringers of carbonate and quartz.

Pyroclastics range from ash flows to lapilli agglomerate. Fragments range from mafic to intermediate in composition and are angular to moderately rounded. Mafic volcanic rocks form 1 to 30 m thick units. The mafic metavolcanic unit in the southwestern portion of the Allerston property (Figure 9) is part of a major unit estimated to be 10,000 m thick.

The felsic and intermediate volcanic suite consists of an upper part and a lower part. The lower part is dacitic to rhyolitic in composition. The rocks are flows and tuffs, some of which exhibit welding. The flows are fine grained and the tuffs are probably ash falls. Alteration to quartz-sericite-chlorite schist is common. The rocks weather greenish grey to moderately brown and are bluish grey to greyish green on fresh surfaces.

The upper part of the felsic suite contains some rhyodacite but is generally similar to the lower suite. The rocks are largely flows with some tuffaceous units. Chlorite content is notably less than in the lower suite and alteration is largely to quartz-sericite schist. The total thickness of the felsic metavolcanic units has been estimated to be of the order of 2000 m (Bowen *et al.* 1976).

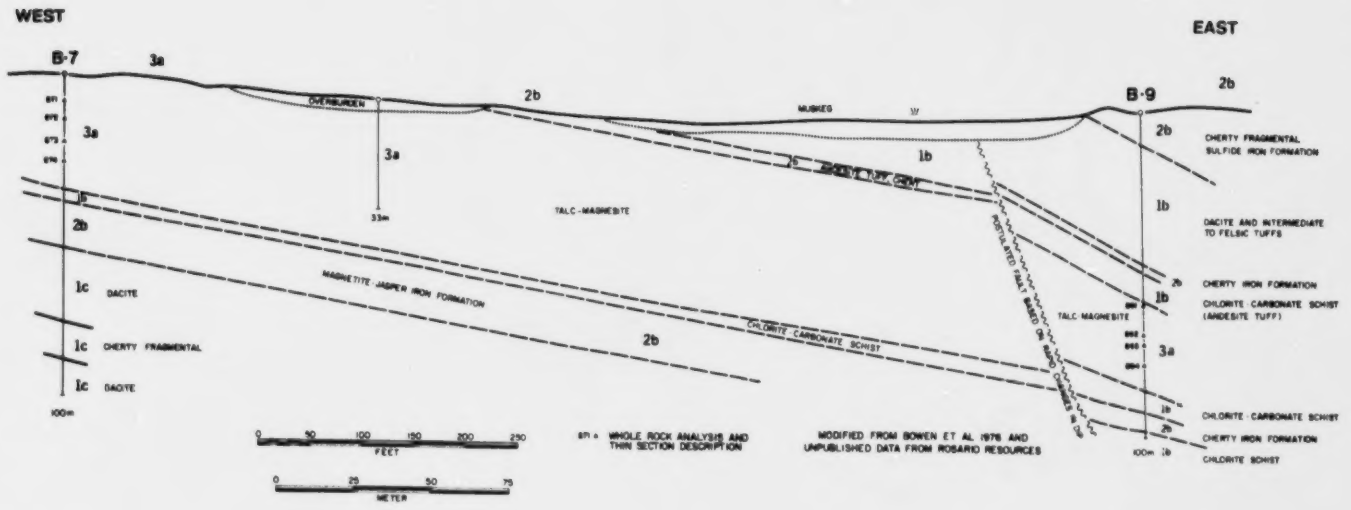


Figure 10. *Geological cross-section of Allerston deposit. Cross-section is east to west between diamond drill holes B-7 and B-9, facing north.*

Iron Formation (Unit 2)

At least three iron formations occur on the property, one predominantly quartz-sulphide, one mainly quartz-graphite and one predominantly oxide. These rocks are all in part pyroclastic.

The lower oxide unit consists of alternating layers of chert, argillite and magnetite. Individual layers are from less than 1 cm to 15-20 cm thick. This unit varies from 3 m to over 30 m in thickness and averages 15 m.

The lower unit is quartz-graphite-sulphide iron formation that is associated with the lower felsic to intermediate volcanic unit. It is partly pyroclastic in origin, especially the cherty graphitic breccia. In the area where it is best exposed, it consists of massive graphite with pyrite-pyrrhotite stringers and cherty to graphitic chert with massive and brecciated pyrite with pyrrhotite stringers. Its thickness is 3 m to 30 m and averages 20 m.

A sulphide layer associated with the upper felsic volcanic unit is composed of chert, recrystallized quartz, pyrite and pyrrhotite as stringers and massive sulphide zones. Minor carbonate and chlorite stringers are commonly associated with this zone and anomalously high silver contents (up to 9.78 ounces per ton in grab samples) have been described (Bowen *et al.* 1976, p.16).

Komatiitic Rocks (Unit 3)

These are predominantly flows of dunitic, peridotitic or basaltic composition (see Figure 11, Table 9). Surface textures are only partially preserved. Spinifex textures, polygonal jointing and other textures characteristic of komatiites (see Pyke *et al.* 1973; Kretschmar and Kretschmar 1975; Arndt *et al.* 1977; Arndt *et al.* 1979 for detailed descriptions of surface texture and chemistry) can be seen in only a few localities and are completely absent in the highly altered dunitic talc-magnesite ore. Analyses of bulk samples and trace element analyses (discussed below), however, confirm their komatiitic chemistry. The talc-magnesite ore occurs in the extensively altered dunitic portion of a thick sill or flow (see cross-section, Figure 10).

The weathered surface of the talc-magnesite zone is greyish brown and has a characteristic pock-marked appearance due to the preferential weathering of magnesite. Fresh surfaces are generally light grey, or greenish grey if the chlorite content is higher. Fine-grained to medium-grained magnetite is common and most rocks are magnetic.

In the talc-magnesite zone, carbonate veins 1-2 cm wide are not uncommon, but are volumetrically minor. Quartz veins were not noted in the talc-magnesite zone and are rare in the peridotite. In a few places, asbestos veins occur in the peridotite. Talc veining in the talc-magnesite zone is common and ranges from 1 mm stringers to 5 cm wide veins. One talc vein with 2-3 cm long, 1-2 cm diameter hornblende crystals was noted. Specular hematite often occurs as coarse plates on the contacts of these talc veins (Bowen *et al.* 1976, p.48) and is particularly abundant at sample site 367 in the North Zone (Figure 9).

Intrusive Rocks (Units 4 and 5)

Aplitic intrusions occur in two locations (Figure 9). They are fine-grained (1 mm and smaller grains) and feldspar-, quartz- or biotite-porphyritic. The aplites were interpreted as high level felsic intrusions by Bowen *et al.* (1976).

Northwest-trending diabase dikes occur in several locations. They are quartz-poor and have a fine- to medium-grained texture.

Structure and Metamorphism

The structure of the area was described by Bowen *et al.* (1976) as follows:

> "Foliations trend generally NE (010 to 060°) and dip 10° to 30°N. Locally foliations trend NW (with dips to SW at 10 to 60°) or NE to E-W with dips 10-50°N or S, indicating a series of gentle folds which may be part of a large

structure. A series of gently undulating folds occur in the west central part of the property.

"There is a possibility that thrusting could account for the repeated sequence of talc-magnesite, felsic to intermediate volcanics, and iron formations in the South Zone area. Breccia and shear zones are noted both in the field and in drill core, especially in the graphite iron formation and mafic volcanics near the contacts."

Metamorphic grade is greenschist facies.

MINERALOGY AND CHEMISTRY

Extensive work has been carried out on the talc-magnesite zones by Bowen *et al.* (1976). Three new whole-rock analyses are presented in this report. Chemical analyses reported by Pyke (1980) for the host rocks are also presented below.

The average modal compositions of North and South Zones, based on thin section examination, whole-rock chemical analyses and CIPW norm calculation, reported by Bowen *et al.* (1976) are given in Table 7.

Individual modal analyses of North and South Zone bulk samples, and South Zone drill core samples are shown in Table 8. These were carried out by Toni Fischer and are reported in Bowen *et al.* (1976).

In the North Zone, carbonate crystals range from 0.5 to 3 mm in the east to 2-6 mm in the western portion. Glomeroporphyritic aggregates of carbonate in the east, grade to anhedral crystals in the west. Relics of olivine (now carbonate) are enclosed in a dirty groundmass of fine talc and chlorite, which contains fine black granular opaques. Talc laths are rarely over 2 mm in length and most are 1 mm or less. Chlorite occurs as fine stringers of interstitial aggregates.

South Zone bulk samples are similar to North Zone bulk samples, but one South Zone drill hole (B-5, Figure 9) shows an increase in carbonate grain size down-hole from about 0.5 to 5 mm. This was interpreted by Bowen *et al.* to have been caused by differentiation or crystal settling. Textures range from saccharoidal at the top to glomeroporphyritic down-hole. Some recrystallized silica was encountered at 355 feet. Talc also tends to increase in grain size.

Sixty-three whole-rock chemical analyses are presented in Table 9. Of these, three are new, 51 are from Bowen *et al.* (1976), and nine, mainly of host rocks, are from Pyke (1980). The locations for all of them are shown on Figure 9.

A special norm that uses amount of CO_2 in the whole-rock analysis to derive carbonate was calculated for the analyses by Bowen *et al.* (1976). Means, standard deviations and coefficients of variation were then calculated in order to determine the internal homogeneity of the North and South Zones (Table 10).

Overall, carbonate and talc show the least variation. Chlorite content is extremely variable. No statistically significant difference between North and South Zones is apparent, although Bowen *et al.* 1976 concluded from hole B-5 that there is evidence of differentiation in the South Zone. The implication is that the mineralized body is relatively homogeneous.

TABLE 7. AVERAGE MODAL COMPOSITION OF TALC-MAGNESITE ZONES, ALLERSTON DEPOSIT.

	North Zone	South Zone	
	Bulk Samples	Drill Core	Bulk Samples
No. of samples	12	20	12
Carbonate	41.6%	47.2%	42.4%
Talc	42.2	41.5	40.4
Chlorite	8.7	6.1	11.8
Opaques	7.5	5.2	5.4

TABLE 8. MODAL ANALYSES (VOLUME PERCENT) OF TALC MAGNESITE ROCK ALLERSTON DEPOSIT.

Analysis No.	Sample No.	Carbonate	Talc	Chlorite	Opaques
		North Zone Bulk Samples			
4	354	40	39	6	15
6	356	50	40	5	5
8	358	60	29	6	5
9	359	35	54	5	6
10	360	45	35	8	12
12	362	40	44	6	10
13	363	35	45	12	8
15	365	40	47	6	7
18	368	35	42	15	8
20	370	40	41	15	4
21	371	40	46	8	6
22	372	40	44	12	4
		South Zone Bulk Samples			
24	374	35	45	12	8
25	375	60	33	4	3
26	376	45	45	3	5
27	377	60	23	13	4
28	378	35	54	6	5
29	379	33	55	6	6
30	380	45	46	4	5
31[1]	381	36	30	-	4
32	382	45	46	3	6
33[2]	383	30	27	-	8
34[3]	384	35	50	-	3
36[4]	UM7	10	38	35	5
		South Zone Drill Core Samples			
39	B51	30	45	15	10
40	B52	60	34	3	3
41	B53	60	32	5	3
42	B61	40	46	8	6
43	B62	45	44	3	8
44	B63	45	45	5	5
45	B64	45	48	3	4
47	B66	50	36	6	8
48[5]	B71	54.7	38.3	3.6	3.4
49[6]	B72	45.2	47.9	3.1	3.8
50	B73	50	40	7	3
51[7]	B74	43.8	47.3	5.5	3.4
52	B81	57	30	8	5
53	B82	42	47	6	5
54	B83	50	42	4	4
55	B84	35	40	15	10
57	B91	40	46	10	4
58	B92	55	34	5	6
59	B93	80	12	6	2
60	B94	54	30	8	8

NOTES: Petrographic description by Toni F. Fischer as reported in Bowen *et al.* (1976). Modes visually estimated except analyses 48, 49, 51.

1. Serpentine 30%.
2. Serpentine 35%.
3. Quartz 12%; talc & chlorite intergrown, minor sericite.
4. Quartz 12%,
5. 2331 points counted.
6. 2134 points counted.
7. 2448 points counted.

TABLE 9. CHEMICAL ANALYSES AND NORMATIVE COMPOSITIONS OF WHOLE-ROCK SAMPLES FROM THE ALLERSTON TALC-MAGNESITE DEPOSIT.

Anal. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Samp. No.	2006	2008	2012	354	355	356	357	358	359	360	361	362	363	364	365	366	367
Major Elements																	
SiO_2	43.36	30.60	32.80	31.9	31.7	31.5	30.5	34.6	34.8	34.8	34.5	30.8	36.8	35.3	31.3	36.3	31.2
TiO_2	0.11	0.06	0.07	0.26	0.16	0.26	0.26	0.13	0.32	0.10	0.26	0.29	0.22	0.32	0.22	0.35	0.29
Al_2O_3	1.97	1.48	1.81	0.7	1.0	1.3	1.1	1.2	2.4	0.7	1.8	1.2	1.9	3.6	0.9	2.5	1.1
Fe_2O_3	10.40	8.41	7.39	7.83	6.60	7.58	6.72	6.33	10.5	9.14	8.82	9.64	8.63	12.3	10.3	8.11	9.54
FeO				(7.05)	(5.94)	(6.82)	(6.05)	(5.70)	(9.54)	(8.22)	(7.98)	(8.67)	(7.77)	(11.1)	(9.3)	(7.3)	(8.6)
MnO	0.10	0.13	0.08														
MgO	33.30	34.74	34.42	34.3	34.3	32.5	34.3	34.6	31.7	33.3	32.2	33.9	31.5	30.9	33.3	32.9	33.1
CaO	0.27	0.34	0.22	0.76	0.45	0.95	0.49	0.42	0.87	0.43	1.28	0.28	1.55	0.34	0.24	0.27	0.29
Na_2O																	
K_2O	0.00	0.02	0.00														
P_2O_5	0.05	0.03	0.03														
H_2O_{tot}	7.63	1.83	1.86	3.11	2.85	5.67	5.09	4.45	7.33	2.93	5.10	4.08	4.82	4.66	8.56	5.72	5.07
LOI	10.13	23.95	22.58														
CO_2	3.09	20.88	19.76	21.4	23.1	20.5	21.8	18.4	12.4	18.7	16.3	20.1	14.8	12.9	15.4	14.1	19.7
TOTAL	100.18	100.40	100.11	100.36	100.16	100.26	100.26	100.13	100.32	100.10	100.31	100.29	100.22	100.32	100.22	100.35	100.29
Trace Elements																	
Ni	2670	2900	3380	240	280	280	280	260	320	250	240	220	250	190	210	140	170
Cr	1020	1850	1850	210	210	280	260	240	170	85	170	180	76	90	54	190	94
Normative Minerals																	
Or		0.2															
An	1.1	2.0	1.2	2.5	3.1	4.8	3.3	2.7	5.4	2.5	6.3	1.8	6.5	2.1	1.6	1.7	1.9
Opx	58.9	7.6	21.7	13.9	14.3	16.8	11.5	28.7	28.2	29.1	24.9	11.1	34.7	34.4	14.4	39.9	15.8
Cpx				1.9		1.3				0.2	1.4		2.4				
Ol	35.3	85.7	71.9	77.6	78.6	73.1	80.8	64.5	61.3	65.0	63.5	82.0	52.7	56.0	79.5	51.7	74.3
Cor	1.8	1.2	1.9		0.2		0.3	0.6	1.0			0.9		3.6	0.6	2.5	0.8
Il	0.2	0.2	0.2	0.7	0.4	0.7	0.7	0.3	0.8	0.2	0.6	0.7	0.5	0.7	0.6	0.8	0.7
Mt	2.6	3.0	3.0	3.4	3.3	3.5	3.5	3.1	3.3	3.0	3.3	3.4	3.1	3.2	3.3	3.4	3.5
Ap	0.1	0.1	0.1														

Table 9. Continued

Anal. No.	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Samp. No.	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384
Major Elements																	
SiO_2	35.6	36.2	32.9	25.7	30.8	35.3	30.5	30.2	29.7	31.1	30.9	32.0	29.7	31.3	31.8	29.8	39.8
TiO_2	0.32	0.29	0.22	0.22	0.42	0.20											
Al_2O_3	1.8	1.9	1.4	1.2	1.1	0.8	0.96	1.12	0.91	1.06	1.11	1.52	0.85	1.04	0.89	0.97	5.32
Fe_2O_3	8.12	7.33	8.51	10.2	7.3	8.58	8.51	7.99	8.38	6.71	7.93	9.31	7.94	7.72	8.38	7.83	9.70
FeO	(7.3)	(6.6)	(7.7)	(9.2)	(6.6)	(7.7)	(7.7)	(7.2)	(7.5)	(6.0)	(7.1)	(8.4)	(7.1)	(7.0)	(7.5)	(7.0)	(8.7)
MnO																	
MgO	32.5	31.6	33.5	34.9	35.7	34.4	34.8	34.6	35.8	35.8	36.1	34.3	35.4	37.3	35.6	38.5	18.9
CaO	0.40	0.64	0.34	0.32	0.43	0.30	0.10	0.11	0.06	0.43	0.05	0.61	0.96	0.33	0.12	0.08	5.6
Na_2O																	
K_2O																	
P_2O_5																	
$H_2O_{tot.}$	5.68	6.23	4.75	3.98	2.97	2.52	4.56	4.63	3.80	2.6	3.2	2.8	2.9	6.3	3.7	5.8	2.3
LOI																	
CO_2	15.9	14.1	18.6	23.7	21.7	18.1	20.4	21.3	21.4	22.3	20.6	19.5	22.3	16.0	19.5	17.0	18.4
TOTAL	100.32	98.29	100.22	100.22	100.42	100.20	100.04	99.97	100.00	100.00	99.97	99.82	100.00	100.00	99.70	99.50	100.00
Trace Elements																	
Ni	160	130	200	320	140	150											
Cr	110	160	150	140	190	90											
Normative Minerals																	
Q				4.8													
An	2.5	4.1	2.2	2.0	2.8	1.9	0.7	0.7	0.4	2.9	0.3	3.9	0.1			2.1	
Opx	37.7	42.5	22.7		8.0	29.7	8.6	9.5	2.9	8.0	8.0	10.2	3.1	2.1	0.8	0.5	18.5
Cpx														3.4	13.5		55.4
Ol	54.3	48.4	70.2	88.8	84.0	64.5	86.7	85.5	92.7	85.8	87.4	82.4	84.8	91.2	81.9	93.6	13.4
Larn													0.9				9.9
Cor	1.4	1.0	1.0	0.8	0.4	0.3	1.0	1.3	1.1	0.4	1.3	0.5		0.6	0.9	1.0	
Il	0.8	0.7	0.5	0.5	1.1	0.5											
Mt	3.4	3.4	3.3	3.1	3.7	3.1	2.9	3.0	2.8	2.9	2.9	2.8	2.9	2.8	2.9	2.7	2.8

Table 9. Continued.

Anal. No.	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
Samp. No.	UM1	UM7	UM45	UM60	B.51	B.52	B.53	B.61	B.62	B.63	B.64	B.65	B.66	B.71	B.72	B.73	B.74
Major Elements																	
SiO_2	32.14	41.48	34.04	39.05	33.9	30.9	33.4	33.5	32.9	33.2	33.0	32.3	29.9	32.4	33.0	33.2	34.1
TiO_2	0.05	0.53	0.15	0.13													
Al_2O_3	1.02	9.17	2.20	2.05	1.9	0.8	1.8	1.7	1.2	1.2	1.5	1.4	1.0	1.7	1.4	1.5	1.9
Fe_2O_3	(11.0)	(11.4)	(9.8)	(14.6)	10.1	5.99	8.35	6.70	6.44	7.05	7.50	6.47	5.42	6.60	7.39	8.10	7.78
FeO	9.90	10.21	8.77	13.17	(9.1)	(5.4)	(7.5)	(6.0)	(5.8)	(6.3)	(6.7)	(5.8)	(4.9)	(5.9)	(6.7)	(7.3)	(7.0)
MnO	0.21	0.21	0.11	0.11													
MgO	36.58	16.30	35.75	33.87	32.26	35.46	33.21	34.22	35.11	35.18	34.32	33.07	32.61	34.42	35.08	35.20	33.79
CaO	0.15	8.05	0.16	0.30	3.19	0.22	0.23	2.07	0.33	0.17	0.28	0.39	6.77	1.28	0.27	0.84	1.01
Na_2O	0.10	1.54	0.02	0.10													
K_2O	0.01	0.04	0.01	0.01													
P_2O_5																	
H_2O_{tot}					5.26	3.57	5.52	2.93	1.33	1.39	1.73	2.51	2.27	3.99	1.05	1.33	2.02
LOI	19.08	10.59	18.32	10.61													
CO_2					13.39	23.06	17.49	18.88	22.69	21.81	21.67	23.86	26.57	19.61	21.81	19.83	19.40
TOTAL	99.26	98.14	99.54	99.40	100.05	100.07	99.99	99.99	99.98	100.00	100.00	100.03	104.54	100.00	100.29	99.99	100.00
Normative Minerals																	
Q													0.1				
Or	0.1	0.3	0.1	0.1													
Ab	0.3	14.9	0.2	1.0													
An	0.9	20.6	1.0	1.7	6.4	1.5	1.5	6.0	2.2	1.1	1.8	2.6	3.6	6.1	1.7	5.2	6.4
Opx		4.9	13.8	28.0	5.2	12.1	26.4	11.0	20.1	21.6	21.8	24.4		11.5	20.6	13.0	20.5
Cpx		20.2			10.5			5.7						1.8		0.1	
Ol	97.4	38.0	82.2	67.5	75.2	82.8	67.5	74.6	75.0	73.4	72.2	69.1	80.8	77.8	73.6	78.8	70.2
Ne	0.4																
Larn													12.6				
Cor	0.7		2.3	1.5		0.5	1.8		0.8	1.2	1.3	0.9			1.2		0.1
Il	0.1	1.1	0.4	0.3													
Mt					2.7	3.0	2.9	2.8	2.9	2.9	2.9	3.0	2.9	2.9	2.8	2.8	2.8

TABLE 9. Continued.

Anal. No. / Samp. No.	52 B.81	53 B.82	54 B.83	55 B.84	56 B.85	57 B.91	58 B.92	59 B.93	60 B.94	61 P72-76	62 P74-76	63 P75-76	64 P76-76	65 P77-76	66 P66-76	67 T464-73	68 T471-73
Major Elements																	
SiO_2	37.9	32.9	32.5	33.01	37.5	32.9	31.9	31.8	33.1	78.2	68.6	63.5	50.5	45.3	27.1	50.02	39.3
TiO_2										0.11	0.45	0.77	0.66	0.57	0.20	0.50	0.18
Al_2O_3	3.3	1.5	1.4	1.6	3.8	1.6	1.1	1.4	1.9	9.55	15.7	13.6	11.9	10.9	1.60	1.30	1.87
Fe_2O_3	10.30	6.77	6.94	7.48	8.79	8.02	6.74	7.13	7.74	0.37	0.77	0.89	0.69	0.60	3.16	8.92	3.20
FeO	(9.3)	(6.1)		(6.7)	(7.9)	(7.2)	(6.1)	(6.4)	(7.0)	2.36	2.60	6.01	7.80	9.03	5.16		3.41
MnO										0.08	0.12	0.13	0.15	0.15	0.10		0.11
MgO	28.43	34.37	34.81	33.65	31.32	32.39	34.03	33.15	32.76	2.52	2.22	3.72	9.55	11.9	28.4	36.7	35.8
CaO	7.22	1.23	1.12	0.45	3.92	3.92	2.18	1.40	2.29	0.82	0.77	1.33	4.92	6.58	0.38	0.53	0.90
Na_2O										0.87	0.14	5.93	3.22	1.28	0.00		0.10
K_2O										1.84	4.13	0.04	0.02	0.02	0.01		0.01
P_2O_5										0.05	0.12	0.07	0.07	0.08	0.04		0.05
H_2O_{tot}	0.03	1.64	0.76	1.59	0.69	0.56	1.22	2.87	2.30	1.62	2.46	2.21	3.81	4.16	0.48		0.40
LOI																	
CO_2	12.88	21.59	22.47	21.23	13.98	20.71	22.83	22.25	19.91	0.78	0.90	1.64	7.60	10.0	31.0		1.20
TOTAL	100.08	99.97	100.00	99.88	100.03	100.13	99.95	99.98	99.99	99.18	98.99	99.92	100.9	100.58	98.64	97.98	97.75
Trace Elements																	
S										0.01	0.01	0.08	0.04	0.01	0.01	0.03	0.02
Ni										5	25	940	660	370	1640	3053	
Cr										10	40	2720	1900	1480	740	4655	
Normative Minerals																	
Q										60.9	47.8	17.3	2.9	1.1			
Or										11.2	25.5	0.2	0.1	0.1	0.1		0.1
Ab										7.6	1.2	52.3	30.4	12.5			1.0
An	10.4	5.4		2.9	12.3	5.6	4.0	5.1	6.7	3.9	3.2	6.4	20.1	27.7	2.4	2.7	4.9
Opx	4.3	14.1		26.4	17.4		4.7	12.0	10.6	10.6	9.5	18.9	38.3	48.3	12.5	68.4	34.0
Cpx	24.7	2.0			8.8	14.3	8.2	3.3	6.3				4.6	7.7			
Ol	47.9	75.5		66.9	57.3	77.0	80.4	76.7	73.6						79.0	24.5	56.0
Larn						0.3	2										
Cor				1.0						4.9	10.3	1.6			1.5	0.3	0.2
Il										0.2	0.9	1.5	1.4	1.3	0.6	1.0	0.4
Mt	2.5	2.9		2.8	2.6	2.8	2.9	2.9	2.8	0.6	1.2	1.3	1.1	1.0	3.7	3.0	2.9
Ap										0.1	0.3	0.2	0.2	0.2	0.1		0.1

TABLE 9. Continued.

NOTES:

Analysis No.	Sample No.	Source	Jensen Plot Classification	Comments
1	2006	this study	PK	talc-magnesite altered
2	2008	this study	PK	komatiite
3	2012	this study	PK	dunite
4-23	354-373	Bowen *et al.* (1976)		20 North Zone Bulk Samples
24-34	374-384	"		11 South Zone Bulk Samples
35	UM1	"	altered	peridotite adjacent to North Zone
36	BM7	"	BK	
37	UM45	"	PK	
38	UM60	"	PK	
		South Zone Drill Core Samples		
39	B51	Bowen *et al.* (1976)	PK	Hole B-5 Sample 9818
40	B52	"	PK	" " 9819
41	B53	"	PK	" " 9821
42	B61	"	PK	Hole 5-6 Sample 9824
43	B62	"	PK	" " 9825
44	B63	"	PK	" " 9826
45	B64	"	PK	" " 9827
46	B65	"	PK	" " 9831
47	B66	"	PK	" " 9832
48	B71	"	PK	Hole B-7 Sample 9833 25 ft.
49	B72	"	PK	" " 9834 45 ft.
50	B73	"	PK	" " 9835
51	B74	"		" " 9836 86 ft.
52	B81	"		Hole B-8 Sample 9840
53	B82	"	PK	" " 9841
54	B83	"		" " 9842
55	B84	"	PK	" " 9843
56	B85	"	PK	" " 9844

TABLE 9. Continued.

		South Zone Drill Core Samples		
57	B91	"	altered	Hole B-9 Sample 9847 180 ft.
58	B92	"	PK	" " 9848 210 ft.
59	B93	"	PK	" " 9849 220 ft.
60	B94	"	PK	" " 9850 240 ft.
61	P72-76	Pyke (1980)	CA	tuff, quartz, sericite schist
62	P74-76	"	CD	tuff, quartz, sericite schist
63	P75-76	"	CB	sheared andesitic tuff
64	P76-76	"	BK	sheared, carbonated. BK
65	P77-76	"	BK	partially carbonated, BK
66	P66-76	"	PK	dunite, carbonated
67	T464-73	"		serpentinized peridotite-dunite
68	T471-73	"	PK	"

Abbreviations:
CA = calc-alkalic andesite,
CD = calc-alkalic dacite,
PK = peridotitic komatiite.
CB = calc-alkalic basalt,
BK = basaltic komatiite,

Analyses 1-3 analyst: M. Gorton, University of Toronto.
Analyses 4-60 analyst: X-Ray Laboratories, Toronto; H_2O determined by subtracting total of major oxides and CO_2 from 100.
Analyses 61-68 analyst: Ontario Geological Survey, Toronto.

TABLE 10. AVERAGE COMPOSITION AND VARIABILITY OF ALLERSTON NORTH AND SOUTH ZONES FROM NORMS.

	North Zone Bulk n = 20			South Zone Bulk n = 10			South Zone Core n = 24		
	mean	s.d.	c.v.	mean	s.d.	c.v.	mean	s.d.	c.v.
Carbonate	34.8	6.7	0.19	38.3	4.0	0.10	39.2	6.4	0.16
Talc	44.5	6.0	0.13	50.4	9.0	0.10	40.9	3.8	0.09
Chlorite	8.0	3.9	0.49	5.7	1.0	0.17	9.0	3.7	0.41
Opaques	8.5	1.5	0.18	8.0	0.6	0.8	7.3	1.1	0.15

NOTES:
s.d. = standard deviation of the mean
c.v. = coefficient of variation = s.d./mean
n = number of samples

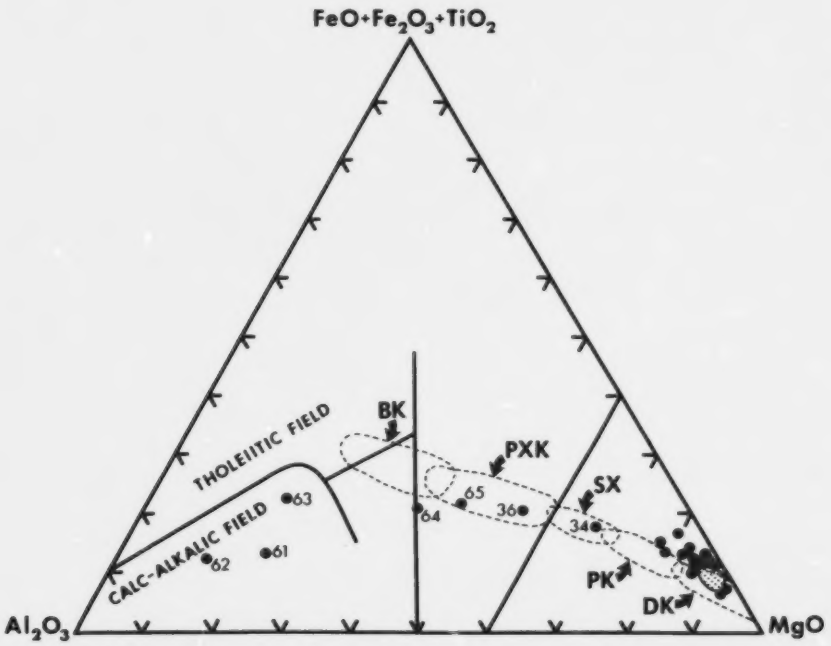


Figure 11. *Jensen cation plot of chemical analyses of whole rock samples from Allerston talc-magnesite deposit. See Figure 7 for definitions of komatiitic fields. A large number of analyses fall in the stippled area within the dunitic komatiite field (DK).*

TABLE 11. COMPOSITIONAL RANGES OF TYPICAL END PRODUCTS OF PROGRESSIVE CARBONATION OF DUNITIC KOMATIITE.

	Canadian Magnesite Mines deposit	Allerston deposit
	%	%
magnesite	55-70	42
talc	15-30	41
quartz	8-16	0
chlorite	0	6-12

Chemical analyses of whole-rock samples (Table 9), are plotted on Figure 11 and show that the host rocks are calc-alkalic andesite, dacite and basalt and komatiitic basalt. All analyses of talc-magnesite samples plot in or close to the field of dunitic komatiite or peridotitic komatiite, except analysis 34 (sample 384 from the South Zone), which represents either spinifex or a more pyroxenitic composition than the others. It is from a thin komatiitic flow in tuffaceous andesite.

Carbonate alteration to talc-magnesite seems not to have substantially changed the bulk chemistry of the altered dunitic komatiite although some analyses fall outside the field of unaltered dunitic komatiite, closer to the F apex (Figure 11). This is further discussed in the section on alteration.

DISCUSSION

1. The initial composition of both the Canadian Magnesite Mines magnesite-talc and Allerston talc-magnesite deposits approximated that of dunitic komatiite with greater than 40 percent anhydrous MgO. The Canadian Magnesite Mines dunite is more strongly carbonate-altered than the Allerston komatiitic dunite. This progressive carbonate alteration is reflected in the end-product rocks with the compositions given in Table 11.

2. The virtual absence of quartz as an alteration product at Allerston permits production of a talc product with low wire-loss abrasion characteristics.

3. The Allerston talc-magnesite deposit is ideally situated, is relatively homogeneous throughout, has a high talc content and is readily accessible through open pit mining methods.

DAFFODIL ASBESTOS DEPOSIT, DELORO TOWNSHIP

The Daffodil asbestos deposit is located 8 km southeast of the town of Timmins (see Figure 2). The holdings include the former Nakhodas asbestos property and cover extensions of the host ultramafic rock both north and south of the Nakhodas in a contiguous block of 27 patented and 10 unpatented claims (Figure 12).

One of the earliest asbestos prospects investigated in this part of Ontario was the Nakhodas which was mined on a very small scale for the recovery of long spinning fibre. Several asbestos producers carried out limited exploration. A total of about 250 tons of asbestos were mined between 1923 and 1957. Several determined efforts to develop the property were made during this time. The most extensive investigation was that of Nicolet Asbestos Mines Limited in 1958-1959 when 10,061 feet of drilling was completed on two claims. A more complete outline of the history of production was presented by Vos (1971).

ECONOMIC GEOLOGY

Information on grade and tonnage of this deposit is from an unpublished report by W.J. Mullins of Watts, Griffis and McOuat Limited, which stated that mapping and drilling indicated at least five fibre zones, almost exclusively on two mining claims. Two of the zones have indicated lengths of 1100 feet or more and widths of 270 feet or more and all are open on strike both to the north and south. In an area of 2000 by 2000 feet the ratio of "ore" to waste is estimated at 3 to 1. Within this area, the two principal zones to a depth of 500 feet have an inferred reserve of 20 million tons. An average 3.23 percent fibre yield has been estimated. There are no actual test results from core samples but three bulk samples from surface outcrops were tested by Canadian Johns-Manville Company Limited and an average of 5.35 percent fibre was recovered and valued at $15.70 per ton of "ore" (1974 prices).

Two main fibre zones occur in the areas of open pit indicated on Figure 13 (Chart A, back pocket). Fibre orientation and fibre zones generally parallel main contacts of the dunite, but in others asbestos has formed interstitially tc polybrecciated dunitic fragments of probable flow origin, and fibres are more randomly oriented.

At the time of writing, the property was being re-evaluated and plans were in progress to mill the ore at the United Asbestos Incorporated plant in Midlothian Township when that mine reopened.

GEOLOGY

Chrysotile asbestos occurs in serpentinized dunite and peridotite in the basal part of a differentiated sill or flow (Figure 13). This ultramafic body is at least 4 km long and 800 m thick (Carlson 1967) and may be longer. The upper differentiate consists of layers of gabbro and pyroxenite that in total are about 20 m thick in the area most highly mineralized with asbestos on the Daffodil property, but about 1.5 km to the north, these layers are more than 100 m thick. There is no hyaloclastite or spinifex at the contact between host pillowed basalts and upper differentiates where this contact is exposed.

The Daffodil sill and host volcanic rocks strike northerly and dip to the east between 70 and 85°. No significant small scale folding is evident and metamorphic grade is greenschist. However, a fault is postulated (Figure 13) because spinifex-textured and massive komatiites (locations 2331, 2332) appear to strike directly into calc-alkalic basalts near Maynard Lake and as well, the Daffodil sill seems to be offset to the east, south of Maynard Lake.

Volcanic host rocks to the ultramafic body are basaltic komatiite and well-pillowed calc-alkalic basalt which clearly indicate tops to the west. Pillows are small and locally there are feldspar and hornblende phenocrysts. A thin tuffaceous interflow sediment occurs in the volcanic rocks at the southwest end of the property and a similar unit is being mined for gold at the Faymar Mine directly to the east of the Daffodil open pits. None of the thinner ultramafic units in the host sequence exposed to the north of the Daffodil property and along strike from the

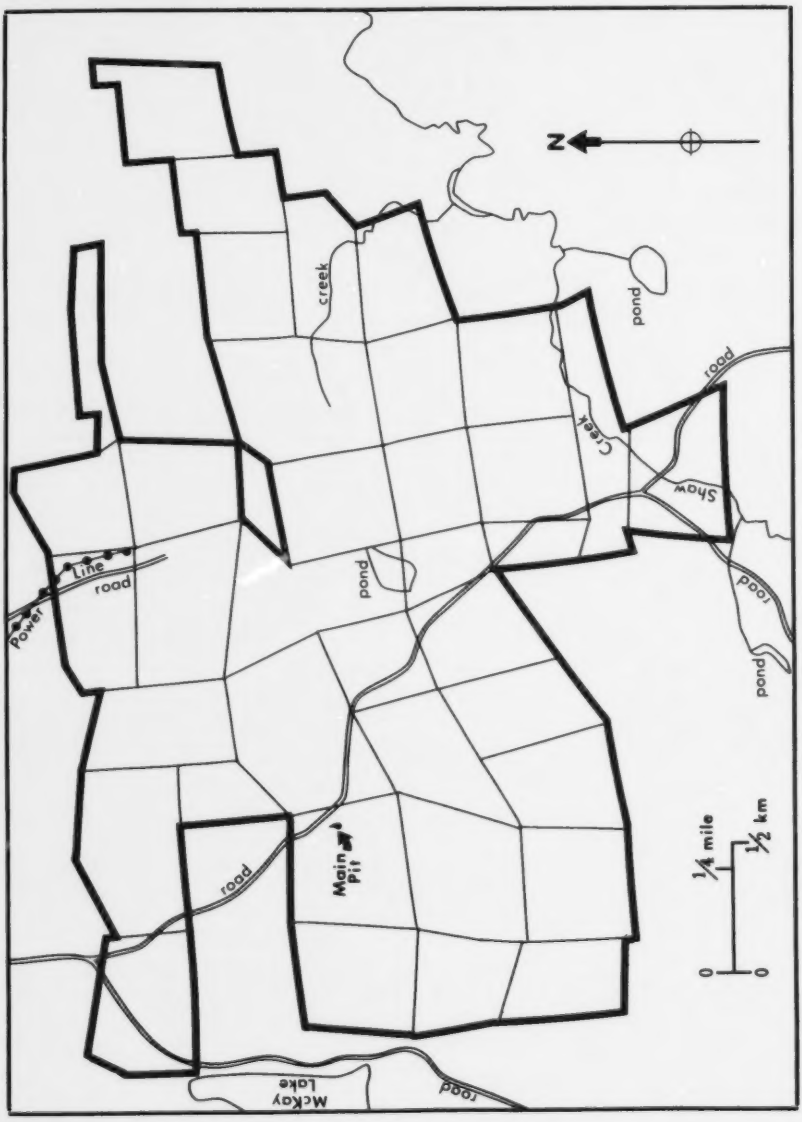


Figure 12. *Claim map of Daffodil asbestos deposit, Deloro Township.*

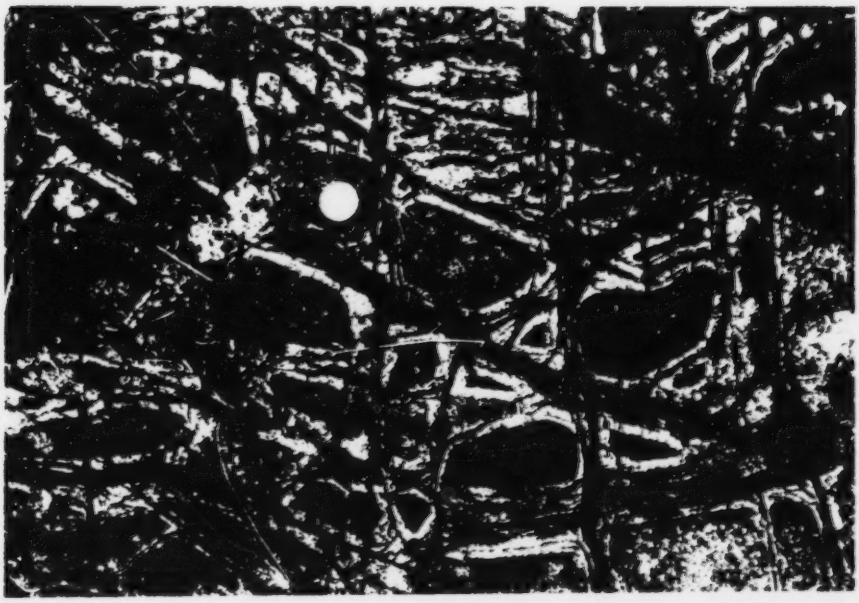


Photo 2. *Chrysolite asbestos veins have formed interstitially to polyhedral dunitic breccia fragments at Daffodil asbestos deposit. Location near sample 2322. Diameter of coin is 2 cm.*

Daffodil dunite are komatiites on the basis of field evidence such as surface textures, but relations are obscured by intrusion of a granitoid pluton in that area. The serpentinite that hosts asbestos is predominantly light green to dark green, is translucent and forms blocky and rounded outcrops. Weathering colours vary from almost white (serpentinized peridotite) to orange brown (demonstrating incipient carbonate alteration in serpentinized dunite). Good cumulate textures are common on weathered surfaces.

South of the southern open pit are 1-2 m thick zones of light green carbonate-altered dunite alternating with darker green asbestos-bearing layers. These zones trend northwesterly, parallel to the main contacts.

The potentially most significant feature of the Daffodil sill is polyhedral breccia textures in the basal dunitic part (Photo 2). Similar textures in Munro Township and elsewhere where they are well developed (Photo 3), are taken to be diagnostic of komatiitic flows by Arndt *et al.* (1979). These polyhedral breccia textures occur directly to the south and along strike of the main fibre zone near sample location 2322, and at the south end of the Daffodil property, near sample location 2333.

The presence of these polyhedral breccia textures, together with the chemical criteria discussed below, strongly suggest that the Daffodil sill is a differentiated flow. The implications for asbestos formation are discussed after the chemical and mineralogical evidence has been examined.

MINERALOGY AND CHEMISTRY

Fourteen whole-rock chemical analyses and CIPW norms of samples from the Daffodil sill and host volcanic rocks are presented in Table 12. Sample locations for all but a few samples are plotted on Figure 13. The exceptions are sample 2334, from dunitic komatiite south of the Daffodil property, which may be the Daffodil sill, or may be an underlying komatiitic sequence, sample 2342, a peri-

Photo 3. *Polyhedral jointing in massive ultramafic komatiite from Lamotte Township, Quebec. Note the similarity of this texture to that in Photo 2. Same scale as Photo 2.*

dotitic komatiite, and sample 2344, a carbonate-altered basalt, both from the northern terminus of the Daffodil sill.

All analyses in Table 12 are plotted on Figure 14, except sample 2330, which is from a strongly carbonate-altered ultramafic rock and contains 0.4 percent nepheline in the CIPW norm.

From Figure 14, it is evident that the host volcanic rocks are calc-alkalic basalts (samples 2336 and 2344). Sample 2339, also a volcanic rock from the basal part of the Daffodil sill, falls in the tholeiitic field but this rock has field characteristics very similar to the basalts overlying the Daffodil sill and may be an altered calc-alkalic basalt.

The upper pyroxenitic differentiates, samples 2320 and 2323 are slightly more iron-rich than peridotitic komatiite but are not unequivocally tholeiitic in nature because the analyses do not fall on the differentiation trend, e.g. Theo's flow (see Arndt 1975 and discussion of Munro sill chemistry in this report).

All other samples plot in or very close to the field of dunitic komatiite on Figure 14.

DISCUSSION

1. Chemical criteria for a komatiitic origin of the Daffodil sill are not unequivocal, but in conjunction with the polyhedral textures, they strongly suggest that the Daffodil sill is a differentiated flow.

2. The most important implication of a flow origin for some asbestos-hosting ultramafic rocks is that an environment of asbestos formation existed in addition to the prograde and retrograde environment of Wicks and Whittaker (1977). Wicks (1978) summarized previous work and suggested that a mild metamorphism, coupled with faulting, fracturing, shearing or folding is required to produce chrysotile asbestos deposits. Based on our observations, we suggest that the open

TABLE 12. CHEMICAL ANALYSES AND NORMATIVE COMPOSITIONS OF WHOLE ROCK SAMPLES FROM THE DAFFODIL ASBESTOS DEPOSIT.

Analysis No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sample No.	2313	2320	2322	2323	2327	2330	2331	2333	2334	2336	2338	2339	2342	2344
Major Elements														
SiO_2	35.40	42.65	37.22	44.22	37.42	35.62	57.82	38.58	36.38	55.91	38.87	50.42	40.17	42.98
TiO_2	0.05	0.21	0.06	0.29	0.09	0.05	0.55	0.04	0.06	0.74	0.04	0.81	0.0	0.91
Al_2O_3	0.96	4.76	1.27	4.97	1.91	1.21	11.33	0.97	1.24	15.91	0.97	15.14	0.36	13.83
Fe_2O_3	7.51	5.43	6.47	3.90	9.12	4.35	2.07	5.94	4.76	2.19	6.34	3.47	0.90	1.12
FeO	-	8.10	2.06	7.10	1.26	1.99	9.36	1.06	0.53	5.77	1.46	9.89	2.72	5.91
$FeO_{tot.}$	(6.8)	(13.0)	(7.9)	(10.6)	(9.5)	(5.9)	(11.2)	(6.4)	(4.8)	(7.7)	(7.2)	(13.0)	(3.5)	(6.9)
MgO	39.37	26.48	35.19	24.80	35.35	33.39	11.37	37.29	35.86	5.14	37.34	6.77	27.4	4.95
CaO	0.03	4.10	1.76	7.15	1.12	5.84	1.36	1.48	4.33	8.47	0.20	7.34	9.91	9.51
Na_2O	0.0	0.14	0.0	0.28	0.0	0.08	0.0	0.0	0.09	2.84	0.0	1.99	0.0	0.39
K_2O	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.33	0.0	0.06	0.0	4.08
P_2O_5	0.02	0.04	0.03	0.04	0.05	0.06	0.12	0.05	0.08	0.17	0.06	0.07	0.03	0.24
$H_2O_{tot.}$	13.72	7.82	11.14	6.45	11.39	10.48	6.34	11.72	10.56	1.75	11.33	3.63	3.60	2.06
CO_2	0.76	0.08	4.09	0.14	1.62	6.88	0.32	2.82	5.69	0.16	3.13	0.17	15.06	14.13
TOTAL	99.65	99.85	99.37	99.35	99.51	100.01	100.65	100.05	99.62	99.41	99.83	99.76	100.15	100.13
Trace Elements														
S	-	0.04	0.08	0.01	0.16	0.06	0.01	0.10	0.04	0.03	0.09	0.0	0.0	0.02
Ni	3457	1046	2425	1326	1994	2555	285	2685	2879	126	2159	170	2126	205
Cr	2395	3503	6707	2360	4707	1724	218	1450	1902	191	2907	1915	1053	396
Normative Minerals														
Q							33.7			12.1		6.4		
Or	0.2									2.0		0.4		28.7
Ab		1.3		2.6					0.9	24.7		17.6		3.9
An		13.5	4.1	13.3	6.1	3.6	6.3	3.1	3.6	30.5	0.7	33.6	1.2	28.5
Opx	16.3	38.3	22.7	30.5	23.9		45.6	26.1	3.9	16.3	35.3	33.6	11.7	9.4
Cpx		6.8	4.7	19.7		22.2		4.1	16.9	9.2		3.2	46.1	21.1
Ol	79.4	38.8	65.2	30.4	63.5	69.7		63.6	71.4		60.0		39.2	3.5
Larn						0.9								
Cor	1.1						9.7				0.9			
Il	0.1	0.4	0.1	0.6	0.2	0.1	1.1	0.1	0.1	1.4	0.1	1.6		2.1
Mt	2.7	2.7	2.7	2.8	2.7	2.7	3.2	2.6	2.7		2.6	3.5	1.6	1.9
Ap	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.2	0.4	0.2	0.2	0.1	0.7

TABLE 12. Continued

NOTES
Analysis 1, Analyst: M. Gorton, University of Toronto;
Analyses 2-14, Analyst: V. Kubat, Ecole Polytechnique, Montreal.

S in wt. %. Cr and Ni in ppm. Norms are CIPW.

Analysis No.	Sample No.	Field Description	Jensen Plot Classification
1	2313	Carbonate altered serpentinized dunite from dump	peridotitic komatiite
2	2320	upper pyroxenitic differentiate	peridotitic komatiite
3	2322	asbestos-bearing dunite	peridotitic komatiite
4	2323	pyroxenitic layer	peridotitic komatiite
5	2327	asbestos-bearing dunite	peridotitic komatiite
6	2330	carbonated chlorite-talc rock, possible spinifex. 0.4% Ne in norm	altered, norm contains 0.4% Ne
7	2331	basaltic komatiite flow	basaltic komatiite
8	2333	dunitic komatiite with flow breccia texture	peridotitic komatiite
9	2334	dunitic serpentinized komatiite with asbestos fibres, south of Daffodil property	peridotitic komatiite
10	2336	dark, dense, fine grained basalt	calc-alkalic basalt
11	2338	massive serpentinized asbestos-bearing dunite	peridotitic komatiite
12	2339	dark, dense, basalt	tholeiitic basalt
13	2342	carbonated peridotite, north end of Daffodil sill	peridotitic komatiite
14	2344	carbonate-chlorite altered basalt, north end of Daffodil sill	calc-alkalic basalt

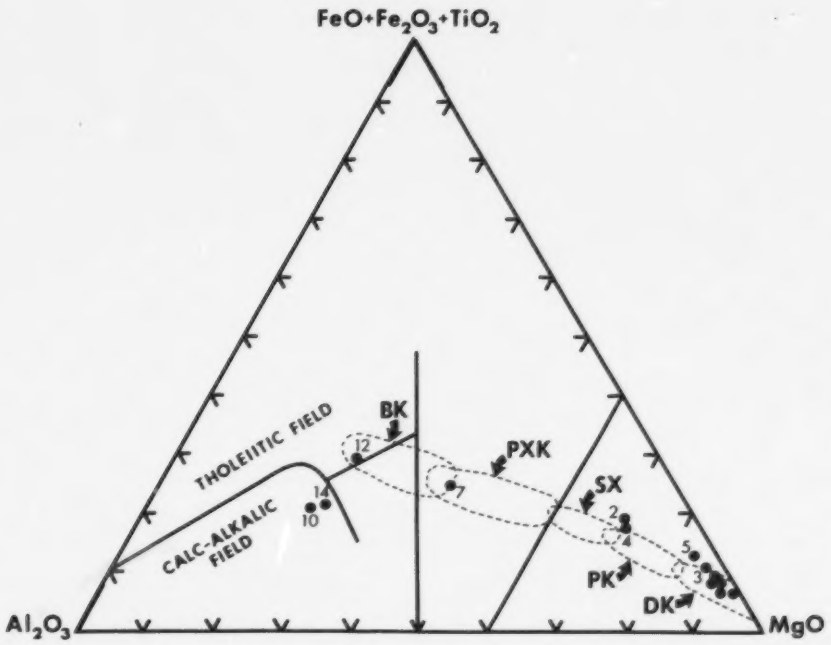


Figure 14. *Jensen cation plot of chemical analyses of whole-rock samples from asbestos-bearing Daffodil sill and host rocks. See Figure 7 for definitions of komatiitic fields.*

structures necessary for easy access of hydrothermal asbestos-forming solutions can be provided by the interstices of polyhedral breccia fragments and other structures resulting from flowage.

Further discussion of asbestos formation in Archean komatiites is deferred to a later discussion of the alteration process in general.

SLADE–FORBES ASBESTOS DEPOSIT, DELORO TOWNSHIP

The Slade-Forbes asbestos deposit is located in southeast Deloro Township, about 3 km southeast of the Daffodil asbestos property and consists of one claim, P.6886. A total of about 611 tons of asbestos was produced on the property between 1917 and 1957. There has apparently been no activity since then. A more complete outline of the history of this mine was presented by Vos (1971), Hewitt and Satterly (1953) and Ross (1931).

ECONOMIC GEOLOGY

The deposit was described by Hewitt and Satterly (1953) as follows:

> "Chrysotile asbestos occurs in cross-fibre veinlets in granular serpentinized dunite of apple-green colour.
>
> "An open pit 40 ft. square and 10-15 feet deep was sunk by the Slade-Forbes Asbestos Co. Asbestos veinlets are up to 2 in. wide and are rather harsh.
>
> "In the open pit, a fault is exposed striking east-west and dipping 75°N. One set of fractures, carrying fibre, parallels this fault; another set strikes N10°E and also carries fibre. In the open pit the fibre appears to make up approximately 5 percent of the rock and is exposed over an area of about 50 feet in diameter."

GEOLOGY

From geological map P.342 (Carlson 1967), it appears that the asbestos fibre at the Slade-Forbes Mine occurs in the same dunitic sill or flow as the Daffodil asbestos deposit, although no upper differentiates have been described and tops are unknown. Unfortunately, there is very little surface exposure and a lack of critical field evidence in the area.

In the area of the main workings there are two pits (Figure 15). Exposures near these pits show development of chrysotile asbestos veins in a uniformly serpentinized dunite that locally has good cumulate textures. South of the northern pit, narrow zones of talc-carbonate rock (about 7 m wide) alternate with chrysotile-bearing serpentinized dunite. These zones trend northeasterly. Striking parallel to the direction of veining are two beds of basaltic komatiite about 25 m thick. One of these is exposed south of the main pit and the other south of the southern pit. A third basaltic komatiite with a similar strike occurs near the waste pile (Figure 15) where it is in contact with calc-alkalic basalt. The contact between the calc-alkalic basalt sequence and the asbestos-bearing dunite strikes north and is therefore probably a fault contact.

Further south, a contact between calc-alkalic basalt and dunite trends northeasterly and dips 60°SE. A thick northeast-trending diabase dike cuts the sequence to the south of the main open pit and a thin northwest-trending felsite dike cuts the main asbestos zone to the north.

MINERALOGY AND CHEMISTRY

Seven whole-rock chemical analyses of asbestos-bearing dunite and host volcanic rocks are presented in Table 13. Figure 16 is a Jensen cation plot of these analyses. The host volcanic rocks plot in the field of calc-alkalic basalt (sample 2212) and basaltic komatiite (sample 2210). Analyses of samples 2211 and 2218 from thin units interbedded with asbestos-bearing dunite confirm their field identification as pyroxene spinifex or pyroxenitic komatiite. Sample 2218 is strongly carbonated spinifex or pyroxenitic komatiite. Samples 2215 and 2216 represent asbestos-bearing dunite from fibre zones south of the main workings. They plot in the field of dunitic komatiite on Figure 16. Sample 2200 is from a thin talc-carbonate zone south of the main pit (Figure 15) and also falls into the field of dunitic komatiite on Figure 16.

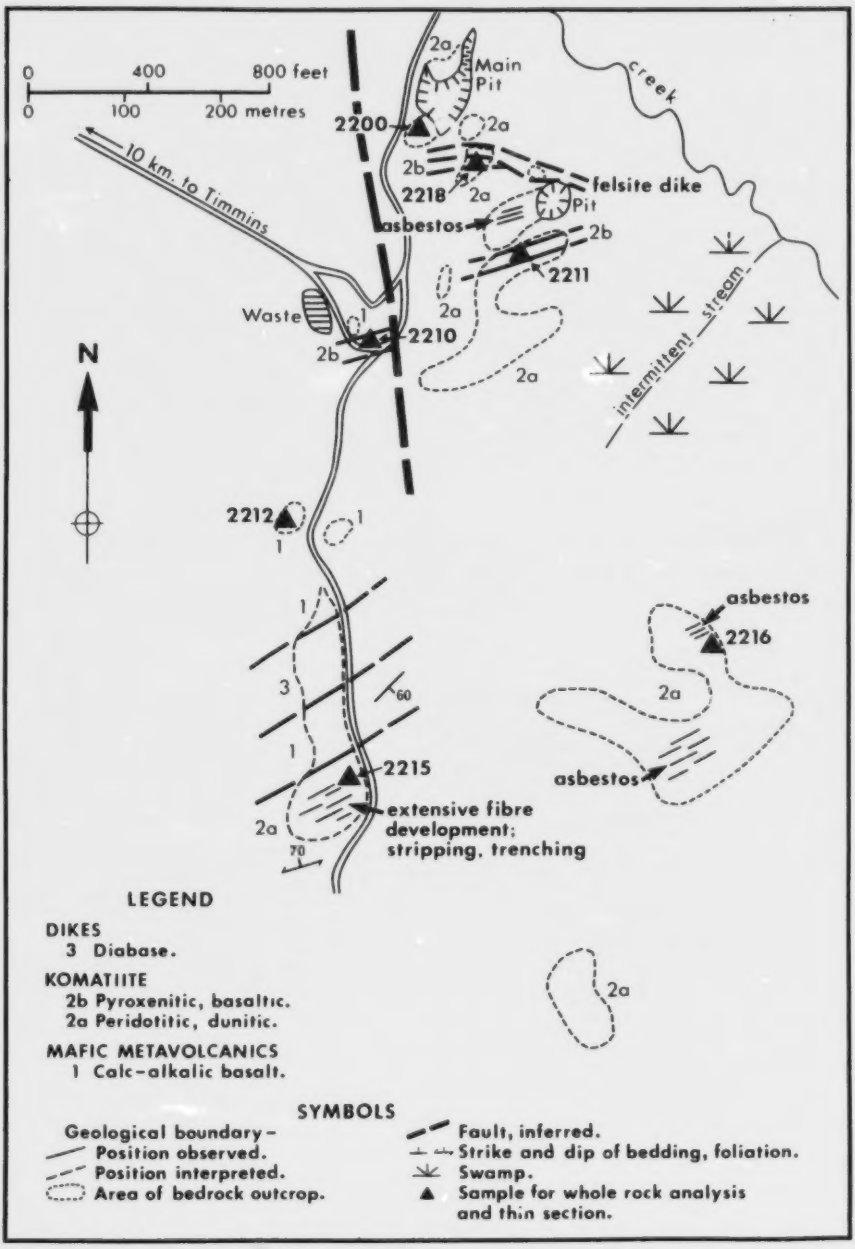


Figure 15. *Geology and sample locations, Slade-Forbes asbestos deposit. Geology by U. Kretschmar.*

TABLE 13. CHEMICAL ANALYSES AND NORMATIVE COMPOSITIONS OF WHOLE-ROCK SAMPLES FROM THE SLADE-FORBES ASBESTOS DEPOSIT.

Analysis No.	1	2	3	4	5	6	7
Sample No.	2200	2210	2211	2212	2215	2216	2218
Major Elements							
SiO_2	33.38	48.13	28.58	54.46	35.55	38.73	37.82
TiO_2	0.05	0.84	1.30	0.89	0.05	0.01	0.66
Al_2O_3	1.18	14.54	18.59	15.05	1.19	0.17	8.06
Fe_2O_3	6.84	1.38	3.98	1.21	9.58	3.74	1.59
FeO	-	7.90	14.73	7.10	2.52	2.46	9.36
$FeO_{tot.}$	(6.2)	(9.1)	(18.3)	(8.2)	(11.1)	(5.8)	(10.8)
MgO	35.97	7.12	20.56	6.30	34.35	37.92	18.42
CaO	0.29	6.94	0.55	6.52	2.10	0.11	7.13
Na_2O	0.0	4.05	0.0	4.01	0.0	0.0	0.08
K_2O	0.0	0.0	0.0	0.98	0.0	0.0	0.0
P_2O_5	0.05	0.17	0.10	0.19	0.03	0.05	0.07
$H_2O_{tot.}$	3.42	4.19		2.09	11.1	10.41	5.86
CO_2	19.27	4.95	0.95	0.57	2.98	6.20	10.36
TOTAL	100.25	100.22	100.91	99.37	99.51	99.84	99.41
Trace Elements							
S	0.0	0.01	0.0	0.0	0.06	0.04	0.0
Ni	3300	220	143	157	2293	2270	836
Cr	1516	180	307	273	4447	1573	1505
Normative Minerals							
Q				2.2			
Or				6.0			
Ab				35.1			0.8
An	1.5		2.3	20.9	3.8	0.3	26.0
Opx	19.1		27.8	22.6	10.6	36.1	28.2
Cpx				9.2	6.5		12.8
Ol	75.2		42.0		76.0	60.5	27.7
Cor	1.0		20.2			0.1	
Il	0.1		2.8	1.7	0.1		1.5
Mt	2.9		4.6	1.8	2.7	2.6	2.8
Ap	0.1		0.3	0.5	0.1	0.1	0.2

NOTES:
Analysis 1 Analyst: M. Gorton, University of Toronto.
Analyses 2-7 Analyst: V. Kubat, Ecole Polytechnique, Montreal.
S in wt. %. Cr and Ni in ppm. Norms are CIPW.

Analysis No.	Sample No.	Field Description	Jensen Plot Classification
1	2200	talc-carbonate altered dunite	peridotitic komatiite
2	2210	basalt	basaltic komatiite
3	2211	spinifex or basaltic komatiite	basaltic komatiite
4	2212	basalt	calc-alkalic basalt
5	2215	asbestos-bearing dunite	peridotitic komatiite
6	2216	asbestos-bearing dunite	peridotitic komatiite
7	2218	chloritic-carbonated spinifex or basaltic komatiite	basaltic komatiite

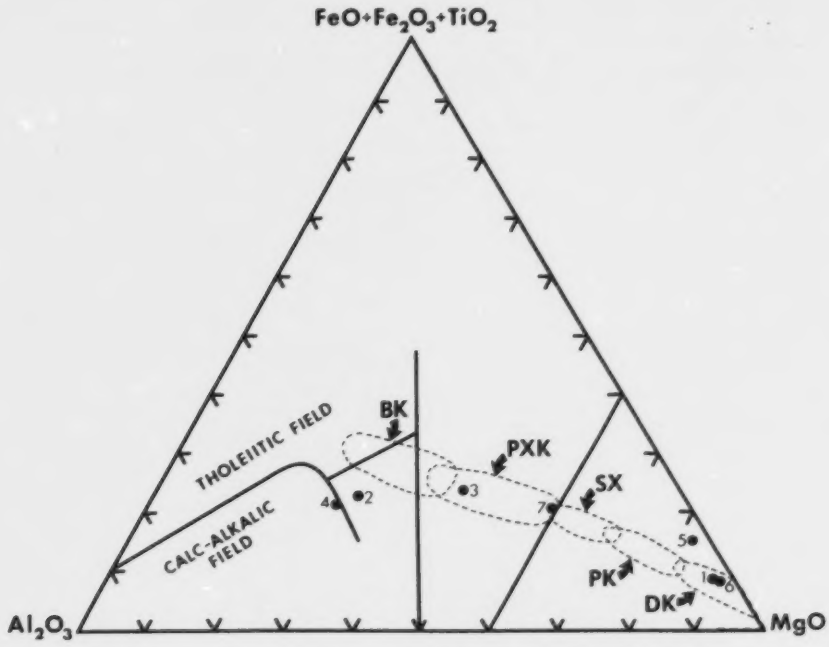


Figure 16. *Jensen cation plot of chemical analyses of whole-rock samples from Slade-Forbes asbestos deposit. Samples include asbestos-bearing dunite and host rocks. See Figure 7 for definitions of komatiitic fields.*

DISCUSSION

Chrysotile asbestos in the Slade-Forbes asbestos deposit is hosted by serpentinized dunite that is interbedded with flows of clearly komatiitic affinity. Probably the host dunite is also komatiitic, although no clear field evidence was seen and chemical analyses of massive dunite alone, without upper differentiates are not readily classified as komatiitic or tholeiitic (see discussion of this point under Munro deposit).

Deposits of Midlothian Township

GENERAL GEOLOGY

The regional geology of Midlothian Township has been most recently mapped by Marshall (1947) and by Bright (1970) from whom the following description is taken.

> "Midlothian Township occupies the eastern part of a felsic volcanic dome which also covers the adjacent townships of Halliday and Sothman. This dome, known as the Halliday dome, lies near the western flank of the Round Lake granitic batholith. Felsic (dacitic to rhyolitic) metavolcanics in the central area of the Halliday dome are interstratified with and surrounded by intermediate (andesitic to dacitic) metavolcanics. On the northeast margin of the dome, metasediments are intercalated with minor disconformity between a younger and older volcanic series. The metavolcanics and metasediments along the margins of the dome occupy axial areas of tight folds. Ultramafic and mafic sills and stocks occur in the outer rhyolitic strata of the dome and younger Matachewan-type diabase dikes occupy some of the north-trending faults and fractures that traverse Midlothian Township. Flat-lying Huronian Gowganda Formation sedimentary rocks in the eastern part of Midlothian Township are intruded by a few small diabase dikes and sills."

STRATIGRAPHIC POSITION OF THE UNITED ASBESTOS DEPOSIT

Bright (1970, p.11) described the relationships in the rocks hosting the United asbestos deposit:

> "In Midlothian Township and adjacent townships, mafics and ultramafics occur in a belt along the southern and western margins of the Halliday dome. Sills and stocks ranging from serpentinite to diorite intrude the outer rhyolitic strata of the dome and are essentially concordant with the invaded strata. Dense, greenish black serpentinite and fine-grained grey gabbro form sharp contacts with the massive rhyolitic rocks and irregular contacts with fragmental rhyolite or dacite.
>
> "Green to greenish black peridotite, pyroxenite and dunite form a large part of the belt near Rhyolite Lake and the northwest arm of Lloyd Lake. A large sill or stock underlying the northwest arm of Lloyd Lake has a peridotite-dunite center and a pyroxenite-gabbro marginal phase. Most of the narrower ultramafic intrusions are serpentinized throughout."

UNITED ASBESTOS DEPOSIT, MIDLOTHIAN TOWNSHIP

United Asbestos Incorporated's Midlothian mine is located about 65 km south of Timmins in Midlothian Township. Two chrysotile asbestos zones occur in the dunitic central portion of the differentiated Lloyd Lake Complex (Figure 17, Chart B, back pocket). There is a long history of exploration of the property, starting in the 1920s. In 1950 Canadian Johns-Manville Company Limited drilled 17 holes totalling 9508 feet. In 1953 Dominion Gulf Company drilled an unknown amount. Canadian Exploration Limited drilled eight holes totalling 5000 feet in 1954. In the years 1971 to 1973 the ore zones were essentially completely outlined in 74 diamond drill holes totalling 29,000 feet and a decision to go into production was made. A mine and mill complex with a rated capacity of 1.1 to 1.3 million tons per year was constructed at a cost of $60 million and production commenced in October, 1975. About 25,000 tons of fibre were produced from about 1.5 million tons of ore in the period of 1-1/2 years to March, 1977, when combined political and economic factors resulted in closure of the mine and mill. At the time of writing, plans were underway to re-open the mine but the economics are tied to the US housing market and to the recommendations on air standards of an Ontario Government Royal Commission that has recently been convened. The above information is from United Asbestos Incorporated records and Kirkland Lake Resident Geologist's files (Ontario Ministry of Natural Resources).

ECONOMIC GEOLOGY

There have been several independent estimates of grade and ore reserves for the North ore zone. The most recent of these and currently preferred is an unpublished 1981 computer evaluation by Donner and Grey for United Asbestos Incorporated, which shows 24.721 million tons grading 4.70 percent of predominantly 5R fibre with some 6D. The value of the fibre is taken to be $554 per ton (P.M. Malouf, Consulting Geologist, personal communication, 1981).

If the South ore zone is included, total ore reserves for the United Asbestos deposit exceed 150 million tons.

With the present milling circuits, 5R fibre is the main objective because the market for 7R or 7M fibre is limited. Recovery is 4.5 percent average for 5R and 3.5-6 percent average for shorter fibre. Grades between 7D and 5M can be achieved.

In the North ore zone, in cross-section, there is a fairly definite concentration of longer fibre within a central tabular zone along strike, surrounded by a larger zone containing predominantly 7D fibre. Ore grade is uniform to the currently explored depth of 120 m (John Hagan, United Asbestos Incorporated, personal communication, 1980).

Cross-fibre chrysotile asbestos is the main mineral in the ore zones. Neither brucite nor talc are present in significant amounts in the open pits or in the mill circuits (Bruno Boisvert, United Asbestos Incorporated, personal communication, 1980).

Minor nemalite and its alteration products pyroaurite-brugnatellite are present but no fibrous amphibole asbestos group minerals were found by M.A. Vos (1976, unpublished internal report, Ontario Geological Survey) in a mineralogical study of the ore.

United Asbestos fibre is characterized by high strength and good drainage.

GEOLOGY

Two chrysotile asbestos zones occur in the center of a zoned differentiated ultramafic sill or flow that is about 900 m thick and is exposed for a strike length of about 2900 m along both sides of a northern arm of Lloyd Lake (Figure 17, Chart B, back pocket). The name Lloyd Lake Complex is proposed for the ultramafic body and is used throughout this report. At its eastern extremity, the Lloyd Lake Complex has been traced by airborne and surface magnetic surveys and diamond drilling for an indefinite extent. It is covered by flat lying to gently tilted, undifferentiated Gowganda sedimentary rocks which consist mainly of conglomerate, arkose, greywacke and sandstone and are about 30 m thick. The western end of the Lloyd Lake Complex is cut off by the Mitt Lake fault with major left-hand displacement (Bright 1970).

The immediate host rock of the ultramafic body is predominantly dacite which is commonly variolitic. Minor andesite and rhyolite also occur. Elsewhere, host volcanic rocks are interlayered with komatiitic volcanic rocks which range in composition from dunite to peridotite. Spinifex is olivine spinifex and is poorly preserved. Dunitic flows were observed in core from drill holes S-2 and S-3 on the south shore of Bray Lake (Figure 17). South of the diversion trench there are at least two sequences of dunitic flows, interlayered with dacite. Rocks mapped as gabbro in this area may be a differentiate of dunitic flows or sills or they may be intrusive. A third area of dunitic komatiite is in a bay on the south shore of Lloyd Lake.

The Lloyd Lake Complex and host volcanic rocks generally trend east and dip steeply to the north or vertically. On the north side of the complex, bedding in pyroxenite layers dips 60-80°N but on the south shore, dips as shallow as 35° were observed in one location. There is no evidence that isoclinal folding could be responsible for these dips, but this has been suggested (John Hagan, personal communication, 1980).

The evidence for tops is conflicting. Flattened amygdules in dacite suggest the sequence is south facing. Poorly preserved olivine spinifex textures, in overlying lenses, indicate tops to the north. Tops to the north are also indicated by differentiation sequence in the Lloyd Lake Complex. Taking all evidence together, including regional considerations, tops are most likely to the north.

The complex is dominated by a central olivine-rich core that is between 500 and 600 m thick. It consists of rhythmically alternating layers of dunite (light green in colour) and peridotite (darker green to almost black). The northern margin (and probably top) is up to 230 m thick and consists of gabbroic differentiates alternating with layers of dunite and peridotite. The gabbroic phases range from a diabasic margin to pyroxenite and plagioclase-rich leucogabbro (subordinate). A gabbroic layer up to 50 m thick was also found in drill holes M-27 and M-28 in the centre of the West Pit ore zone. Locally there is a 1-2 m thick zone of quench olivine between gabbro and underlying dunite.

Outcropping to the north of the East Pit ore zone and forming the northern limit of asbestos-bearing dunite, is a very siliceous, fine-grained light grey rock. In the field it has the appearance of quartzite and was mapped as a xenolith, but a thin section is largely composed of feldspar, pyroxene, and quartz. Its CIPW norm composition is 20 percent pyroxene, 65 percent feldspar and 13 percent quartz (analysis 4, sample 2808, Table 14), which suggests it may be a fine-grained pyroxenite or diabase. It plots in the field of calc-alkalic andesite on the Jensen cation plot (Figure 18). It appears to be limited to this one locality, an area about 90 by 300 m in extent, and may be a chilled offshoot of the thick north-trending diabase dike that cuts through the East Pit ore zone.

A 15-30 cm thick rodingite dike occurs due south and about 200 m stratigraphically below the siliceous unit (Figure 17).

MINERALOGY AND CHEMISTRY

Whole-rock chemical analyses of the major units in the Lloyd Lake Complex and host rocks are presented in Table 14 and are plotted on a Jensen cation plot (Figure 18). Analysis 4, sample 2808 has been described above. Analyses 1, 2, 3, and 5 (samples 2804, 2805, 2806 and 2813) plot in the field of pyroxenitic komatiite. The first of these (2804) is a basaltic komatiite from a sequence overlying the Lloyd Lake Complex (see Figure 17). The others represent the chilled margin and an internal gabbroic unit. Analyses 7 and 8 (samples 2834 and 2835) represent serpentinized dunitic komatiite with cumulate olivine texture from the same overlying sequence. The former of these has a virtually identical composition to analysis 6 (sample 2821) which is a cumulate-textured serpentinized dunite underlying the East Pit ore zone.

Analysis 9 is from United Asbestos Incorporated files and represents average 6D pit ore chrysotile asbestos.

DISCUSSION

1. Chemical analyses of the central dunite in the Lloyd Lake Complex and the overlying dunitic komatiite plot in the field of dunitic komatiite on the Jensen cation plot (Figure 18). As well, both the chilled margin and an internal gabbroic unit plot as komatiites. This chemical similarity suggests a komatiitic origin for the Lloyd Lake Complex but in the absence of flow textures, spinifex or overlying hyaloclastites which are the diagnostic elements in "Fred's komatiitic flow" in Munro Township (Arndt 1975; Arndt *et al.* 1977), a flow origin for the Lloyd Lake Complex cannot be assumed.

Further discussion of the chemistry of differentiated flows and sills is presented with the description of the Munro deposit.

2. There is much further work that could be carried out on the Lloyd Lake Complex but the following would be of immediate scientific and economic interest.

TABLE 14. CHEMICAL ANALYSES AND NORMATIVE COMPOSITIONS OF WHOLE- ROCK SAMPLES FROM THE UNITED ASBESTOS DEPOSIT.

Anal. No.	1	2	3	4	5	6	7	8	9
Samp. No.	2804	2805	2806	2808	2813	2821	2834	2835	X9
Major Elements									
SiO_2	40.29	45.64	47.25	59.51	51.16	35.35	34.37	34.78	41.63
TiO_2	0.55	0.40	0.50	0.79	0.66	0.01	0.01	0.43	0.004
Al_2O_3	10.94	9.76	12.55	16.41	11.28	0.01	0.20	7.56	0.23
Fe_2O_3	1.55	1.05	1.12	1.07	1.35	3.50	4.57	4.29	1.27
FeO	11.14	9.48	9.42	6.03	8.89	1.32	0.59	2.52	0.98
$FeO_{tot.}$	(12.5)	(10.4)	(10.4)	(7.0)	(10.1)	(4.5)	(4.7)	(6.4)	
MgO	20.34	16.69	13.23	3.62	10.53	43.20	38.17	36.20	40.08
CaO	7.78	11.35	10.89	5.88	11.43	0.11	3.39	0.22	0.42
Na_2O	0.01	0.08	0.73	4.10	1.80	0.00	0.00	0.01	0.026
K_2O	0.01	0.01	0.51	0.64	0.34	0.01	0.00	0.01	0.006
P_2O_5	0.01	0.02	0.00	0.20	0.05	0.00	0.00	0.03	-
$H_2O_{tot.}$	6.77	5.08	3.67	2.06	2.63	15.36	11.73	13.68	14.91
CO_2	0.20	0.20	0.10	0.10	0.20	0.30	6.80	0.30	
TOTAL	99.59	99.77	99.97	100.41	100.32	99.19	99.90	100.10	100.20
Trace Elements									
S	0.00	0.01	0.00	0.00	0.00	0.02	0.07	0.07	
Ni	1300	500	300	60	250	4600	3900	1500	
Cr	6500	2200	1500	170	1100	1800	1700	1700	
Normative Minerals									
Q				12.7	0.4				
Or	0.1	0.1	3.1	3.8	2.1	0.1		0.1	
Ab	0.1	0.7	6.4	35.3	15.6			0.1	
An	32.2	27.8	30.6	24.9	22.3		0.7	1.0	
Opx	20.0	30.5	26.2	16.9	27.4	7.8	12.6	23.3	
Cpx	7.6	25.6	20.6	2.8	25.8	0.5			
Ol	36.6	13.1	10.3			89.0	82.7	62.7	
Larn							1.2		
Cor								8.4	
Il	1.1	0.8	1.0	1.5	1.3			1.0	
Mt	2.4	1.6	1.7	1.6	2.0	2.6	2.7	3.3	
Ap				0.5	0.1			0.1	

(a) A petrochemical and field study of the nature of the differentiation might establish the chemical affinity of the magma and might provide details of asbestos genesis in differentiated sills.

(b) A study of the regional and local tectonics on the south flank of the Halliday Dome might establish whether isoclinal folding could be responsible for repetition of the asbestos zone. To know this would be obviously advantageous for the mining of asbestos at deeper levels.

TABLE 14. Continued

NOTES
Analyst: V. Kubat, Ecole Polytechnique, Montreal.
S in wt. %. Cr and Ni in ppm. Norms are CIPW.

Analysis No.	Sample No.	Field Description	Jensen Plot Classification
1	2804	Basaltic komatiite, skeletal olivine (80%) in glassy recrystallized groundmass	basaltic komatiite
2	2805	Pyroxenitic margin. Large fresh pyroxene (70%), serpentinized olivine (20%), twinned plagioclase (10%), minor oxide	basaltic komatiite
3	2806	Gabbro. Fresh pyroxene, plagioclase, serpentinized olivine, minor quartz	basaltic komatiite
4	2808	Very fine grained siliceous-looking rock. Quartz, feldspar, pyroxene (50%), minor magnetite	calc-alkalic andesite
5	2813	Gabbroic margin. Pyroxene, plagioclase, minor serpentinized olivine, magnetite, zircon	basaltic komatiite
6	2821	Serpentinized dunite. Light green colour. Serpentinized olivine (90%), pyroxene, magnetite	peridotitic komatiite
7	2834	Slightly carbonated serpentinized dunite. Serpentinized olivine (90%), talc (5%), patchy carbonate and oxide (5%). Diamond drill hole S-3	altered
8	2835	Serpentinized dunite. Cumulate texture. Serpentinized olivine (95%), oxide (5%). Diamond drill hole S-3	peridotitic komatiite
9	X9	6D chrysotile asbestos fibre, selected from average pit ore. Analysis by Ontario Research Foundation, Toronto. Courtesy United Asbestos Inc.	

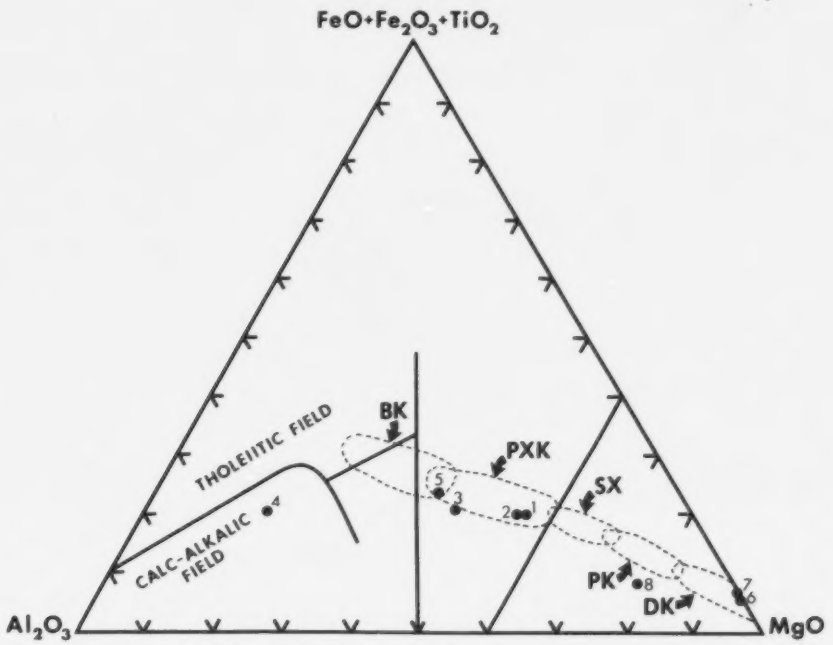


Figure 18. *Jensen cation plot of chemical analyses of whole-rock samples from United Asbestos deposit. Samples include asbestos-bearing Lloyd Lake ultramafic complex and host rocks. See Figure 7 for definitions of komatiitic fields.*

Deposits of Munro, Harker and Garrison Townships

REGIONAL GEOLOGY AND STRATIGRAPHIC POSITION OF THE ASBESTOS DEPOSITS

The area is located 80-100 km east of Timmins in the center of the Abitibi Belt. The belt as a whole has been studied by Goodwin and Ridler (1969) and the geology of the townships has been mapped by Satterly (Munro Township, 1952a; Harker Township, 1952b; Garrison Township, 1949).

Munro, Harker and Garrison Townships lie within a west-northwest-trending belt of mafic and ultramafic lavas and large asbestos-bearing layered sills. This belt, which was named the Munro group by Arndt (1976) and is part of the Stoughton-Roquemaure Group (Jensen 1980), extends from Garrison Township near the Quebec-Ontario border to at least as far west as Dundonald Township, 40 km northeast of Timmins. It is bounded on the south by the Destor-Porcupine Fault, and to the north it is conformably underlain by a sequence of intermediate and felsic volcanic rocks. Similar assemblages of ultramafic rocks and mafic rocks are known in areas to the south of Timmins (Shaw, Deloro and Sothman Townships) and in the Val d'Or area (Malartic Group). These may be stratigraphically equivalent to the Munro group (Arndt 1976).

Metamorphic grade in the three townships is prehnite-pumpellyite or lower greenschist facies, except in the aureoles of granitic intrusions where grades of amphibolite facies or higher are encountered (Jolly 1978). Most strata are steeply dipping and strike east-southeast. They are folded about tight isoclinal axes which trend between N70E and S60E and are more gently folded about northerly axes. The dominant strike directions of both major and minor faults are northwest and east (Arndt 1976).

HOFMANN ASBESTOS DEPOSIT, HARKER TOWNSHIP

The C.E. Hofmann property in Harker Township consists of 20 patented claims lying along the north boundary of Harker Township (Figures 1 and 19), and about 5 km east of the Garrison (Bird-Ginn) deposit in Garrison Township. It may be reached by a short spur road leading north from Highway 101, 40 km east of Matheson.

Outcrops are not plentiful, except near the northern part of the claim group, in the Ghost Range. Considerable stripping and bulldozing work was done at one time, but the trenches are now overgrown.

Much of the following information is from an unpublished 1962 report for C.E. Hofmann, by A.C. Lee.

The 28 claims comprising this property were staked by the Hofmann family and patented in 1950. An option was given to Gulf Oil and their subsidiary, Dominion Gulf Company who did considerable magnetometer surveying and drilling. Three ground magnetometer surveys were done in 1950 and 1951 and a fourth in 1960. Excellent correlation was obtained between chrysotile fibre and high magnetometer readings. In the parts of the serpentinite containing fibre, readings were between 4000 and 8000 gammas. In 1949 and 1950, drilling consisted of 7022 feet of AXT core in 10 holes. C.E. Hofmann also drilled 3030 feet in 13 holes in 1950 and 1033 feet in 1955. In 1960, detailed drilling was done in 18 holes of AXT core totalling 7110 feet. Surface mapping was also done. The property which is currently owned by Lightval Mines Limited, has lain idle since then.

ECONOMIC GEOLOGY

Chrysotile asbestos occurs in the basal serpentinized peridotite of an east-striking differentiated sill that forms part of the Ghost Range sill (Figure 19, Chart B, back pocket). As a result of all drilling up to the end of 1960, commercial asbestos fibre in places up to 1-1/4 inches long was outlined over a continuous east-west extent of 520 m and a 120 m width and 120 m depth. Other asbestos-bearing intersections were also encountered (Figure 19).

No bulk sampling has been performed but shallow pits were dug in three locations for visual inspection of general fibre characteristics. Laboratory milling of a 100-foot section of drill core by Flintkote Mines Limited in Thedford, Quebec, showed that the sample graded Type 4R on the Quebec Test. Core losses in these samples were 11.6 percent. The Flintkote report stated: "The ore is black and hard, but breaks quite easily in the crusher and jumbo. The fibre is vein fibre with good strength, good filterability and high crudy content. The core indicates an overall lack of short fibres. The cleaned fibres give good Bauer-McNett results and if treated with special graders would still be better".

Further work performed in the 1960s by Lightval Mines Limited determined that "core losses could be computer analysed fairly accurately. The net result was that the average values of fibre were increased almost 300 percent, definitely establishing that there were two commercially viable zones. One of these extends for an east-west length of approximately 0.8 km on claims 40537, 38 and 41 (zone 'A'). A second zone more than 1 km long, joins the first zone immediately to the west and appears to be even richer (zone 'B'). The fibre (at least in Zone 'A') is not as harsh and brittle as at Munro and is a natural grade 4" (Ross Hofmann, written communication, 1981).

GEOLOGY, MINERALOGY AND CHEMISTRY

The upper differentiates of the asbestos-bearing sill are pyroxenite, enstatite gabbro and quartz gabbro according to Satterly (1952b) but our mapping established the presence of diorite with two hornblendes (sample 2706) which has not been previously described. The sill is more pyroxenitic at the base, near its contact with rhyolite, than in the asbestos zones, where it is more magnesian and is closer to dunite in composition.

In 1962, in an unpublished report, A.C. Lee described core containing inclusions of host rock rhyolite in the basal peridotite, which suggested to him that the peridotite is intrusive.

At the southern contact of the sill, the host rock consists of fragmental and feldspar-porphyritic rhyolite flows.

Three chemical analyses are presented in Table 15. Analyses 1 and 2 (samples 2701 and 2702) are peridotites slightly more iron-rich than peridotitic komatiite. An upper dioritic differentiate (analysis 3, sample 2706) plots in the field of calc-alkalic andesite on the Jensen cation plot (Figure 20). The analysis shows 2.2 percent Ne in the norm but no unusual mineralogy or elevated volatile content to suggest alteration.

DISCUSSION

1. There is close similarity between the occurrence of asbestos on the Hofmann property and asbestos at the Munro Mine and the Garrison (Bird-Ginn) deposit in Garrison Township. In all three deposits, asbestos occurs in the basal dunite or peridotite of a large differentiated sill.

2. The Hofmann asbestos deposit is a major fibre deposit that awaits favourable economic conditions for development.

TABLE 15. CHEMICAL ANALYSES AND NORMATIVE COMPOSITIONS OF WHOLE-ROCK SAMPLES FROM THE HOFMANN ASBESTOS DEPOSIT.

Analysis No.	1	2	3
Sample No.	2701	2702	2706
Major Elements			
SiO_2	40.30	39.32	49.45
TiO_2	0.16	0.14	0.22
Al_2O_3	3.72	3.59	18.65
Fe_2O_3	3.82	8.08	0.0
FeO	7.70	5.91	4.31
$FeO_{tot.}$	(11.1)	(13.2)	(4.3)
MgO	33.08	31.24	8.62
CaO	2.88	2.87	11.23
Na_2O	0.0	0.0	2.89
K_2O	0.0	0.02	1.23
P_2O_5	0.05	0.05	0.06
$H_2O_{tot.}$	8.19	8.59	2.79
CO_2	0.07	0.12	0.07
TOTAL	99.99	99.93	99.52
Trace Elements			
S	0.02	0.0	0.0
Cr	3421	3420	649
Ni	1424	1360	133
Normative Minerals			
Q			
Or		0.1	7.5
Ab		10.8	21.2
An	11.1		35.5
Opx	24.2	22.7	
Cpx	3.3	3.7	17.6
Ol	58.2	59.6	15.6
Ne			2.2
Il	0.3	0.3	0.4
Mt	2.6	2.6	
Ap	0.1	0.1	0.1

NOTES:
Analyst: V. Kubat, Ecole Polytechnique, Montreal.
S in wt. %. Cr and Ni in ppm. Norms are CIPW.

Analysis No.	Sample No.	Field Description	Jensen Plot Classification
1	2701	Asbestos-bearing peridotite	peridotitic komatiite
2	2702	Pyroxenite. No asbestos.	peridotitic komatiite
3	2706	Gabbro or diorite. Upper differentiate of sill. Contains two hornblendes.	altered. Ne in norm.

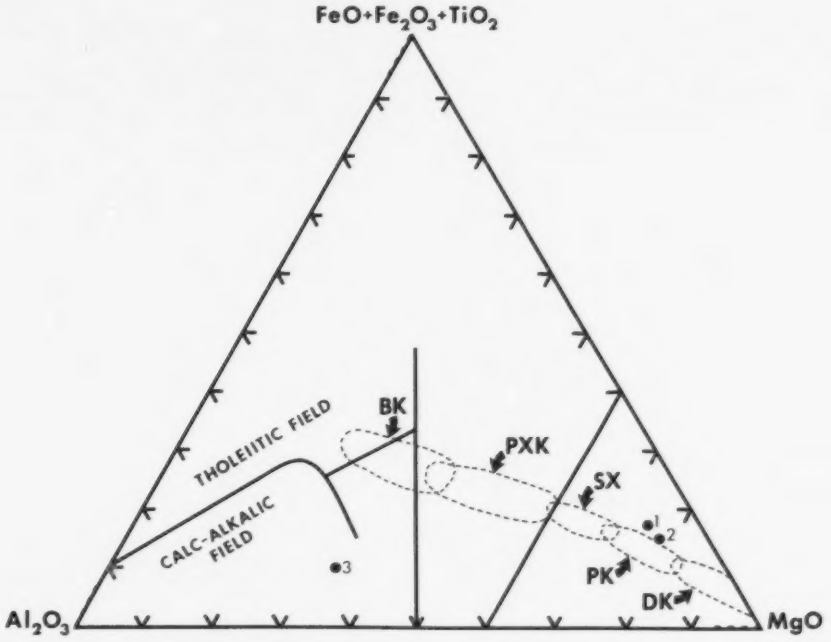


Figure 20. *Jensen cation plot of chemical analyses of whole-rock samples from Hofmann asbestos deposit. Samples include asbestos-bearing peridotite (1, 2) and upper gabbroic differentiate of the Ghost Range Sill (3). See Figure 7 for definitions of komatiitic fields.*

GARRISON (BIRD–GINN) ASBESTOS DEPOSIT, GARRISON TOWNSHIP

The Garrison asbestos deposit, also known as the Bird-Ginn, lies in the northwestern part of Garrison Township (Figure 1, Figure 21, Chart B, back pocket).

The property, owned by Johns-Manville Canada Incorporated, consists of patented claims L56784-5, L56828-9, L58457, the Garrison-East and Garrison-West groups of claims and the McVeigh group.

In 1950 S.J. Bird drilled eight holes totalling 1207 feet and Canadian Johns-Manville Company Limited drilled 14,923 feet in 1951. In 1952 the core claims were optioned by Canadian Johns-Manville from S.J. Bird and in 1956 the company acquired the McVeigh group to secure the down-dip extension of the structure.

The development of the property was described by Vos (1971):

> "In 1968 development work on the property was contracted. A vertical three-compartment 314-foot deep exploration shaft was sunk on claim L54626 and the 632-foot level established at a depth of 294 feet below the collar. In August 1969 a total of 7,735 feet of drifting had been carried out. Six crosscuts at 200-foot intervals were established for bulk sampling purposes. Stockpiles of the samples were kept on surface in preparation of shipment to Asbestos, Quebec. In the orebody veins of 1/8 inch to 1/2 inch wide could be observed, in places forming a maximum of 40 percent of the rock volume. Surface drilling was carried out ahead of underground drifting in order to outline the orebody."

The general geology is shown on the map of Garrison Township (Satterly 1949). Our work consisted of remapping, sampling for whole-rock analyses, and thin section examination. Also, we compiled data on the drilling and location of the asbestos zones, using as our sources the map compiled by Ploeger and Grabowski (1979) and the Resident Geologist's files (Ontario Ministry of Natural Resources, Kirkland Lake).

The deposit was described by Vos (1971) and Hewitt and Satterly (1953).

Two major zones of chrysotile asbestos occur in the basal dunite of a dunite-gabbro complex. The asbestos-bearing dunite is serpentinized and shows good cumulate texture on greenish to white nodular weathering surface. The dunite is green and translucent. Prominent magnetite veins are visible in the open pit area, (samples 2500, 2514, Figure 21) but magnetite veins are subordinate elsewhere. Analyses 1, 2, 4, 5, and 8, (Table 16) represent serpentinized dunite from various locations (Figure 21). Sample 2527 probably represents a thin differentiated dunitic layer in the upper pyroxenitic and gabbroic layers. A chilled leucocratic gabbroic contact is represented by analysis 6, sample 2524. This sample was collected in the vicinity of a shear zone that parallels the gabbro-dunite contact and, although the volatile content of the rock is not elevated, the sample appears to be altered, since it plots in the field of calc-alkalic volcanic rock on the Jensen cation plot (Figure 22) and has nepheline and leucite in the norm (Table 16).

Based on drill hole information, the dunite-volcanic contact to the south of the map-area (Figure 21) dips 45-60°NW (Hewitt and Satterly 1953). The gabbro-volcanic contact on the other hand, appears everywhere to be steeper. Prominent late-stage faults with generally minor displacement and northerly strikes have displaced the fibre zones. Metamorphic grade approximates greenschist facies.

The Garrison deposit appears to be a major fibre deposit awaiting development. Unfortunately, no data on the grade or tonnage of the fibre content is available.

TABLE 16. CHEMICAL ANALYSES AND NORMATIVE COMPOSITIONS OF WHOLE-ROCK SAMPLES FROM THE GARRISON ASBESTOS DEPOSIT.

Analysis No.	1	2	3	4	5	6	7	8
Sample No.	2500	2511	2513	2514	2523	2524	2525	2527
Major Elements								
SiO_2	38.23	38.83	49.39	37.63	37.38	43.03	48.08	37.35
TiO_2	0.09	0.15	1.87	0.12	0.14	0.12	2.09	0.11
Al_2O_3	1.51	2.27	12.97	0.19	2.09	19.13	14.09	2.04
Fe_2O_3	6.48	5.70	2.52	6.54	8.55	0.0	3.35	9.12
FeO	1.59	3.85	14.27	1.39	1.99	3.72	13.67	2.26
FeO_{tot}	(7.4)	(9.0)	(16.5)	(7.3)	(9.7)	(3.70)	(16.7)	(10.5)
MgO	37.98	36.67	5.07	38.04	34.97	9.13	3.60	35.03
CaO	0.16	1.58	6.22	0.23	0.25	19.33	6.79	1.37
Na_2O	0.0	0.0	4.36	0.0	1.12	0.90	4.33	0.0
K_2O	0.00	0.00	0.35	0.0	0.0	0.03	0.07	0.0
P_2O_5	0.04	0.03	0.14	0.05	0.05	0.04	0.16	0.04
H_2O_{tot}	12.68	9.98	2.61	12.97	12.35	4.37	2.47	11.70
LOI								
CO_2	0.62	0.31	0.37	0.43	0.16	0.11	1.50	0.52
TOTAL	99.39	99.39	100.15	98.33	99.08	99.94	100.62	99.58
Trace Elements								
S	0.01	0.02	0.01	0.02	0.03	0.03	0.42	0.04
Ni	5063	4226	82	5234	4324	588	123	5199
Cr	2426	2080	22	2359	2098	245	89	1795
Normative Minerals								
Or			2.01				0.4	
Ab			38.0		11.0		38.6	
An	0.6	7.0	15.2	1.0	0.8	50.4	19.5	6.4
Opx	30.0	21.7	11.5	27.7	5.6		14.1	20.6
Cpx		1.3	13.2		0.2	27.2	12.1	0.9
Ol	64.7	56.8	12.4	67.3	79.0	9.6	5.1	68.9
Larn						4.9		
Cor	1.5			0.7				
Il	0.2	0.3	3.7	0.3	0.3	0.2	4.1	0.2
Mt	2.7	2.7	3.8	2.8	2.8		5.0	2.7
Ap	0.1	0.1	0.3	0.1	0.1	0.1	0.4	0.1

NOTES:
Analyst: V. Kubat, Ecole Polytechnique, Montreal.
S in wt. %. Cr and Ni in ppm. Norms are CIPW.

Analysis No.	Sample No.	Field Description	Jensen Plot Classification
1	2500	asbestos-bearing serpentinized dunite with veins of magnetite	peridotitic komatiite
2	2511	dunite or pyroxenite near contact with upper gabbro	peridotitic komatiite
3	2513	dark, dense basaltic host rock with diabasic texture	tholeiitic basalt
4	2514	green serpentinized dunite	peridotitic komatiite
5	2523	serpentinized dunite with good cumulate texture	peridotitic komatiite
6	2524	chilled leucocratic gabbroic margin of Garrison sill. 4.3% Ne and 0.1% Lc in norm.	altered
7	2525	dense, fine grained host basalt	tholeiitic basalt
8	2527	green serpentinized dunite. Minor chrysotile	peridotitic komatiite

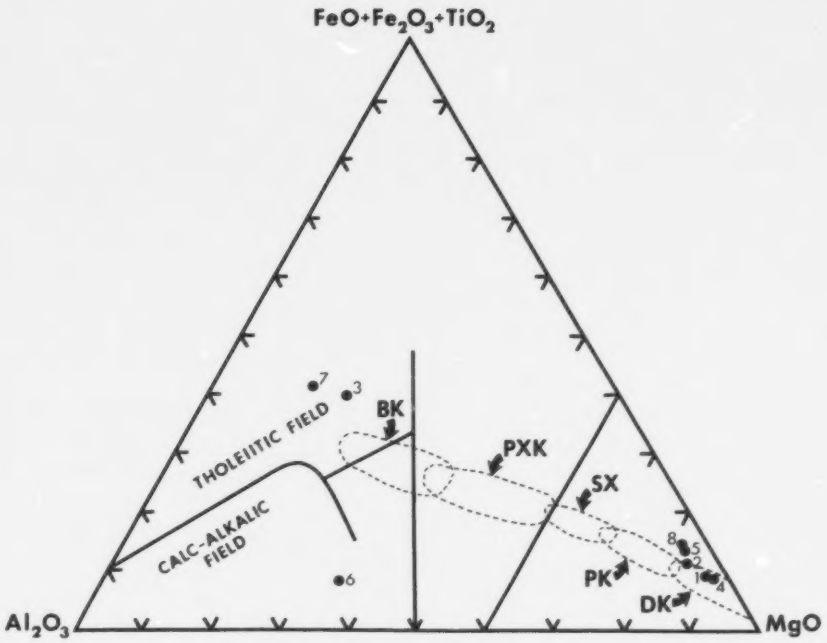


Figure 22. *Jensen cation plot of chemical analyses of whole-rock samples from Garrison asbestos deposit. Samples include basal asbestos-bearing dunite, and upper differentiate and host volcanic rocks. See Figure 7 for definitions of komatiitic fields.*

MUNRO ASBESTOS DEPOSIT, MUNRO TOWNSHIP

The Munro Mine, owned by Canadian Johns-Manville Company Limited, was the largest asbestos mine in Ontario and was in operation between 1950 and 1964. The history and development of the Munro Mine and its geology and orebodies were described by N.W. Hendrey (1951). The geology of the township and the Munro Mine were described by Satterly (1952b), and an overall summary was presented by Vos (1971). These reports present a relatively complete description of the deposits and we will confine the description here to a brief summary of the geology.

The purpose of our study was to try to establish the chemical affinity of the Munro-Beatty sill and host volcanic rocks. With this purpose in mind we mapped two areas of excellent outcrop, areas I and II (Figure 23). Since carbonate alteration destroyed asbestos fibres in the Munro "A" orebody, we briefly examined the

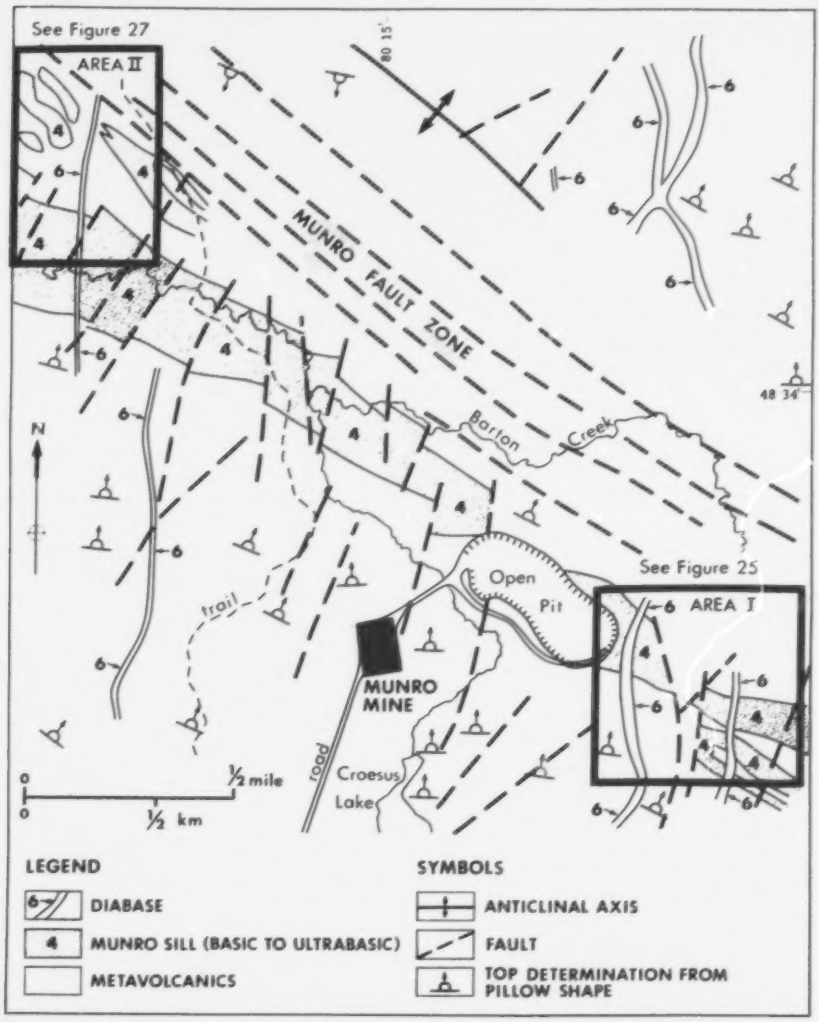


Figure 23. *Generalized geology, Munro Mine and vicinity. Simplified after Satterly (1951b).*

nature of carbonate alteration in an area along strike and to the east of the Munro-Beatty sill (area I). In area II, to the northwest along strike of the Munro "B" orebody and directly overlying the Munro-Beatty sill are komatiitic flows with gabbroic upper differentiates. These flows are very similar in chemistry and field occurrence to the Munro-Beatty sill and it was our intent to see if the Munro-Beatty sill might be a flow.

ECONOMIC GEOLOGY

The chrysotile asbestos orebodies occurred in the basal dunite or peridotite of a differentiated mafic to ultramafic sill which has been traced for a distance of 5.5 km (Figure 23). It has an average strike of N65-70W. The sill varies in width from 300 m at the east end to upwards of 350 m in the vicinity of the Munro-Beatty Townships boundary. It has a vertical attitude or dips steeply south. The sill occurs in intermediate to mafic volcanic rocks. The upper, northernmost portion of the sill is composed of a gabbroic phase approximately 100 m thick. Southward, the gabbro grades sharply into coarse-grained pyroxenite which in turn is in contact with basal dunite and peridotite. The ultramafic zone of the sill varies in width from 150 m in the vicinity of "A" orebody to 275 m near the Munro-Beatty Townships line.

At and near both margins of this ultramafic zone, the rock is dense, dark green to black, serpentinized dunite and peridotite, but toward the central part of the zone this grades into a core of medium to light green, granular, serpentinized dunite. In surface outcrop, the granular serpentine core is white weathering, in contrast to the brownish weathering of the border facies. The important chrysotile asbestos veins occur almost entirely within the limits of the core of granular serpentine.

Three major areas of commercial asbestos fibre occurred over a distance exceeding 3 km. The "A" orebody, at the present site of a water-filled open pit (Figure 23, 24, 25) occurred at the eastern end of the Munro-Beatty sill. Cross-fibre asbestos of a harsh grade in the "A" orebody varied from 1/32 of an inch to a maximum of 1 inch. Magnetite was present as veins directly associated with chrysotile fibres and as disseminations throughout the serpentine.

"B" orebody extends from a major cross fault at the west end of "A" orebody westward along the serpentine band for several hundred feet. Cross-fibre veins range in width from 1/32 of an inch to a maximum of 9/16 of an inch. The fibre is harsh to semi-harsh variety.

"B" extension and "C" orebodies are very similar to each other and are respectively 1.5 and 3.0 km west of "A" and "B" orebodies. The fibre in these areas is paler green in colour than that of "A" orebody and is much softer and silkier in texture. Also, there is very little magnetite. As a consequence, the serpentinite is much lighter green than that in the two areas to the east. The fibre veins range in width from 1/32 of an inch to 1-1/4 inches.

At the eastern end of "A" orebody, and extending at least as far east as the thick north-trending diabase (Figures 23, 25) is a mass of talc-carbonate.

Vos (1971) described the talc-carbonate body as follows (see also Figure 24):

> "The talc-carbonate rock appears to envelop the serpentine mass at its east end. Along both the north and south margins it is present only as a very narrow band, or not at all, on the surface, but in ever increasing width in depth. Also, at a point 770 feet vertically below the surface on the most easterly outcrop of "A" orebody, a diamond drill hole passed from serpentine into talc-carbonate, suggesting that the latter occurs as a great keel on the eastern end of the serpentinite."

GEOLOGY, MINERALOGY AND CHEMISTRY OF AREA I

In area I (Figure 25) the eastern end of the Munro-Beatty sill is cut off by a fault of unknown displacement. To the east of the fault and continuous with the sill, there are two thinner dunite-gabbro sills, one of which probably represents the continuation of the Munro-Beatty sill. Host rocks (unit 2a, Figure 25) are pillowed tholeiitic

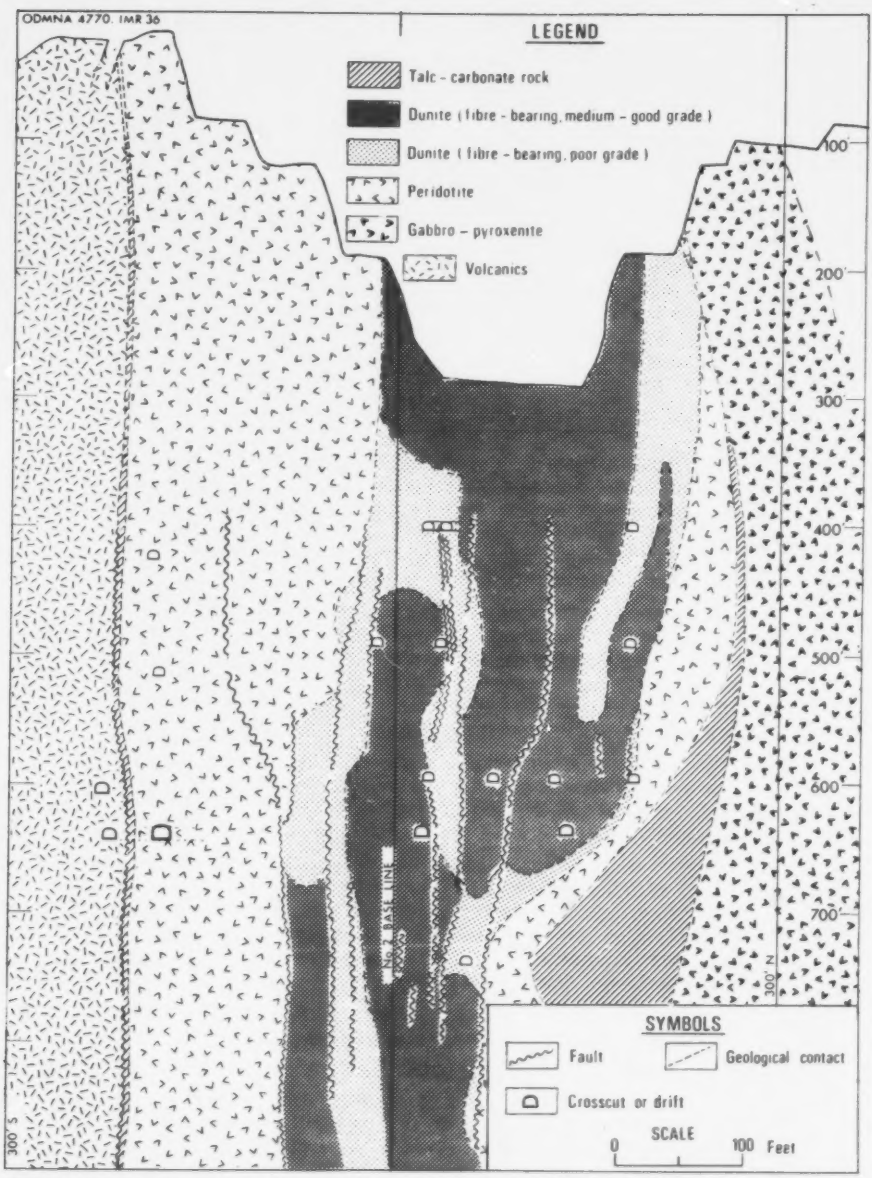


Figure 24. *Cross-section through Munro A orebody. From Vos (1971).*

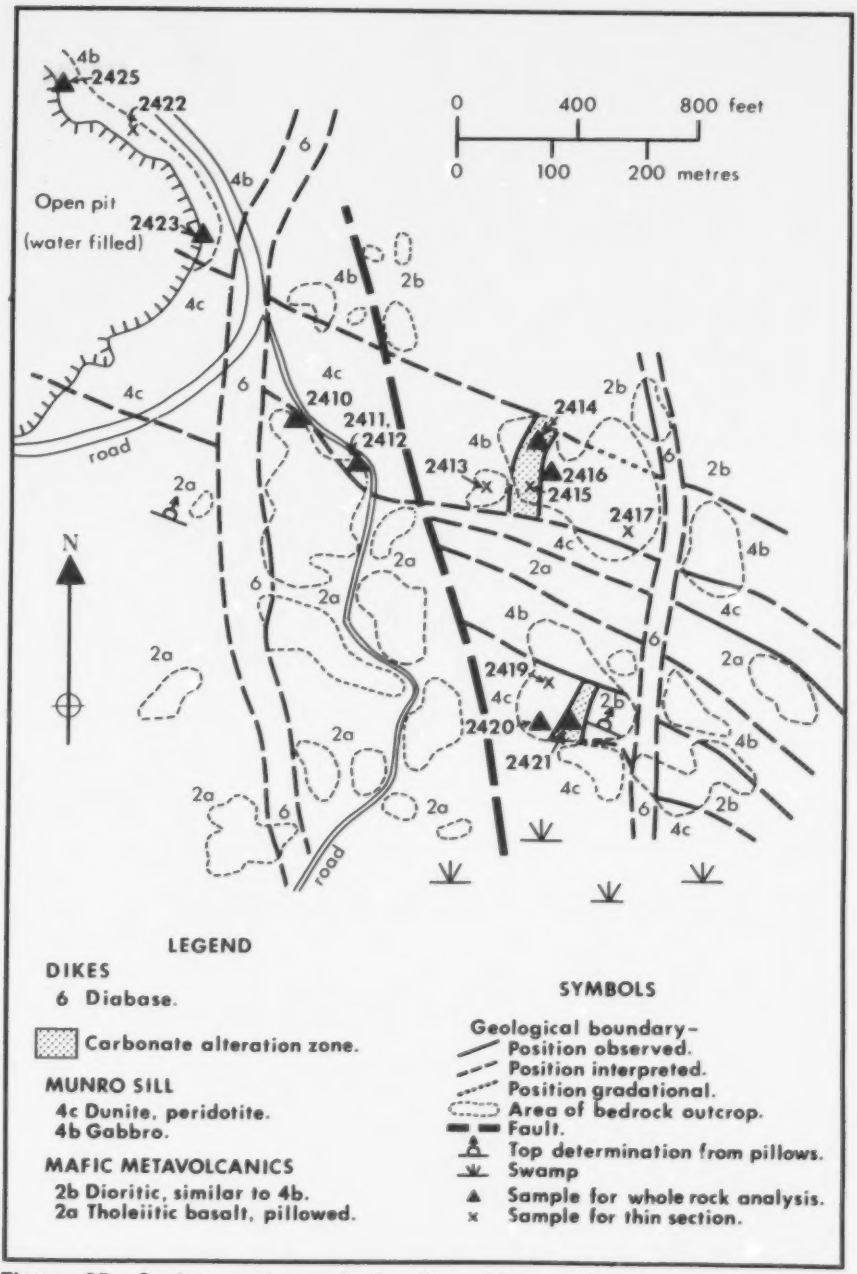


Figure 25. *Geology and sample locations, Munro asbestos deposit, Area I. Geology by U. Kretschmar.*

TABLE 17. CHEMICAL ANALYSES AND NORMATIVE COMPOSITIONS OF WHOLE ROCK SAMPLES FROM THE MUNRO ASBESTOS DEPOSIT.

Analysis No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Sample No.	2410	2411	2414	2416	2420	2421	2423	2425	2426	2601	2602	2605	2606
Major Elements													
SiO_2	51.21	40.14	39.26	50.92	38.24	25.17	33.62	49.87	38.52	38.50	52.17	48.96	50.23
TiO_2	1.85	0.23	0.34	0.85	0.11	0.09	0.16	0.68	0.08	0.13	0.19	1.65	0.58
Al_2O_3	13.39	3.89	5.28	13.43	2.12	1.40	2.75	5.79	1.30	2.46	5.13	14.05	11.0
Fe_2O_3	1.71	5.59	0.07	3.10	7.30	3.89	2.94	1.08	7.13	4.63	0.08	0.19	1.0
FeO	8.36	4.25	7.23	7.90	2.72	5.64	7.90	9.95	1.53	4.45	5.57	13.87	9.16
$FeO_{tot.}$	(9.9)	(9.3)	(7.3)	(10.7)	(9.3)	(9.1)	(10.6)	(10.9)	(8.0)	(8.6)	(5.6)	(14.0)	(10.1)
MgO	7.55	30.78	11.87	6.80	35.35	26.22	27.03	13.87	37.25	33.22	19.51	6.03	13.54
CaO	7.72	2.41	10.32	9.27	0.39	1.96	3.89	13.99	0.14	2.64	13.67	6.69	7.92
Na_2O	4.02	0.0	0.24	2.78	0.0	0.0	0.0	1.26	0.0	0.0	0.93	4.51	2.72
K_2O	0.37	0.0	1.10	0.19	0.0	0.46	0.0	0.06	0.0	0.0	0.04	0.09	0.0
P_2O_5	0.24	0.05	0.04	0.06	0.01	0.02	0.03	0.05	0.05	0.02	0.05	0.14	0.06
$H_2O_{tot.}$	2.79	10.59	1.19	3.12	12.03	0.46	3.84	2.19	12.61	11.86	1.88	3.02	3.04
CO_2	0.90	1.62	22.98	1.56	0.39	34.02	17.43	0.81	0.51	1.76	0.13	0.12	0.04
TOTAL	100.51	99.89	99.95	100.08	98.90	99.65	99.59	99.65	99.38	99.70	99.38	99.36	99.34
Trace Elements													
S	0.40	0.34	0.03	0.06	0.24	0.32	0.0	0.05	0.28	0.03	0.03	0.04	0.05
Ni	121	1967	225	87	2213	871	1291	375	2977	763	364	76	481
Cr	239	4549	2148	150	6978	3386	4789	533	5713	6034	3181	34	1607
Normative Minerals													
Q				3.6									
Or	2.3		8.6	1.2				0.4			0.2	0.6	
Ab	35.2		2.7	24.7				11.0			8.1	39.7	23.9
An	18.0	12.2	13.3	24.8	2.2	3.8	9.6	10.3	0.6	7.8	10.0	18.5	18.5
Opx	18.4	38.7	20.8	21.3	33.6		13.7	18.2	33.6	24.9	24.8	1.7	24.0
Cpx	16.2	0.9	43.4	18.9		0.2	11.8	49.8		5.6	47.1	12.6	17.7
Ol	2.0	43.6	10.0		58.8	84.2	61.4	7.4	60.7	58.3	1.6	23.0	12.9
Larn						3.3							
Cor					1.7				1.3				
Il	3.6	0.5	0.9	1.7	0.2	0.3	0.4	1.3	0.2	0.3	0.4	3.3	1.1
Mt	2.6	2.9	0.1	3.6	2.7	3.6	3.1	1.6	2.7	2.8	0.1	0.3	1.5
Ap	0.6	0.1	0.1	0.1		0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.1

TABLE 17. Continued

NOTES:
Analyst: V. Kubat, Ecole Polytechnique, Montreal.
S in wt. %. Cr and Ni in ppm. Norms are CIPW.

Analysis No.	Sample No.	Field Description	Jensen Plot Classification
1	2410	pillowed green basalt	tholeiitic basalt
2	2411	massive serpentinized peridotite	peridotitic komatiite
3	2414	carbonated quartz-veined basaltic komatiite	basaltic komatiite
4	2416	fine grained gabbro	tholeiitic basalt
5	2420	massive serpentinized dunite	peridotitic komatiite
6	2421	carbonated dunite or peridotite, 3.3% Lc in norm.	altered
7	2423	carbonated upper gabbro of Munro-Beatty sill	peridotitic komatiite
8	2425	unaltered upper gabbro of Munro-Beatty sill	basaltic komatiite
9	2426	asbestos-bearing basal dunite of Munro-Beatty sill. Munro "B" orebody	peridotitic komatiite
10	2601	basal peridotite of gabbro-peridotite flow	peridotitic komatiite
11	2602	upper gabbroic differentiate, gabbro-peridotite flow	peridotitic komatiite
12	2605	polysutured brecciated komatiitic basalt	tholeiitic basalt
13	2606	breccia and spinifex-bearing basaltic komatiites. No spinifex in sample	basaltic komatiite

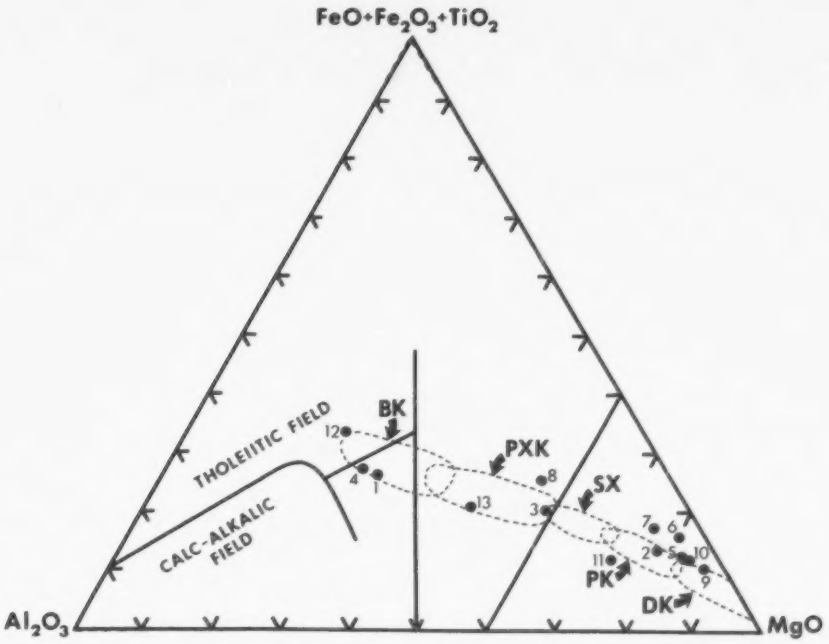


Figure 26. *Jensen cation plot of chemical analyses of whole-rock samples from Munro asbestos deposit. Samples include asbestos-bearing Munro-Beatty sill, upper differentiate, host rocks and komatiitic flows. See Figure 7 for definitions of komatiitic fields.*

TABLE 18. CARBONATE ALTERATION IN AREA I, MUNRO ASBESTOS DEPOSIT.

	Munro-Beatty Sill unaltered gabbro	Munro-Beatty Sill carbonate altered gabbro	Northernmost Area unaltered gabbro	Northernmost Area carbonate altered gabbro	Southernmost Area serpentinized dunite	Southernmost Area carbonate altered dunite
Sample No.	**2425**	**2423**	**2416**	**2414**	**2420**	**2421**
SiO_2	51.4	42.7	53.5	51.8	43.8	38.6
TiO_2	0.7	0.2	0.9	0.45	0.13	0.14
Al_2O_3	6.0	3.5	14.1	7.0	2.4	2.2
Fe_2O_3	1.1	3.7	3.5	0.1	8.4	6.0
FeO	10.3	10.0	8.3	9.5	3.1	8.7
$FeO_{tot.}$	(11.3)	(13.4)	(11.2)	(9.6)	(10.6)	(14.0)
MgO	14.3	34.3	7.1	15.7	40.5	40.2
CaO	14.4	4.9	9.7	13.6	0.45	3.0
Na_2O	1.3	0.8	2.9	0.32	0.0	0.0
K_2O	0.6	0.0	0.2	1.45	0.0	0.7
P_2O_5	0.04	0.04	0.06	0.05	0.0	0.03
H_2O	2.2	3.8	3.1	1.2	12.3	0.46
CO_2	0.8	17.4	1.6	23.0	0.39	34.1

NOTE: Analyses are presented on a volatile-free basis.

TABLE 19. MICROPROBE ANALYSES OF SPINEL AND CARBONATES FROM AREA I, MUNRO ASBESTOS DEPOSIT.

Analysis No.	1	2	3	4	5
Sample No.	2412	2414	2414	2421	2421
			Weight Percent		
Al_2O_3	13.08				
TiO_2	0.22				
Cr_2O_3	49.59				
FeO	25.94	22.30	5.70	9.06	4.86
MgO	7.97	30.63	18.16	41.63	19.03
MnO	0.27	0.23			0.28
CaO			29.17		29.34
SUM	97.07	53.16	53.03	50.69	53.51
			Atomic Proportions		
Al	2.127				
Ti	0.023				
Cr	5.408				
Fe	2.993	6.932	1.765	2.599	1.524
Mg	1.639	16.959	10.018	21.293	10.628
Mn	0.032	0.061			0.089
Ca			11.634		11.676
O	16.000	24.000	24.000	24.00	24.00
CATSUM	12.222	23.952	23.417	23.892	23.917
Mol % $FeCO_3$		19.0	7.6	10.4	6.3
Mol % $CaCO_3$			49.6		49.0

NOTES:

Analysis No.	Sample No.	Description
1	2412	Spinel, average of 5 grains; other analysed minerals in section are pyrite with minor Co, chalcopyrite, pyrrhotite with 1 wt % Ni, serpentine.
2	2414	Magnesite, average of 7 grains; average 0.15 wt % CaO in 4 grains.
3	2414	Dolomite, average of 5 grains; average 0.34 wt % MnO in 3 grains.
4	2421	Magnesite, average of 5 grains; average 0.14 wt % CaO in 3 grains.
5	2421	Ferroan dolomite, average of 4 grains.

or magnesian basalts (12-8.5 weight percent MgO, Naldrett and Smith, in press), or diorite (unit 2b, Figure 25).

The basal dunite is serpentinized and shows cumulate olivine textures. The upper gabbro is medium grained with a diabasic texture that is very similar to unit 2b (Figure 25).

Host volcanic rocks (sample 2410, analysis 1, Table 17) plot in the field of basaltic komatiite on Figure 26. Analyses of basal dunite (2411, 2420, 2426) and upper gabbroic differentiates (2416, 2423, 2425) of these sills are presented as Table 17 and plotted on Figure 26.

There are three areas of intense carbonate alteration (Table 18). Fresh gabbro and its carbonate-altered equivalent from the upper differentiate of the Munro-Beatty sill at the southeast end of the open pit (Figure 25) are represented by analyses 2425 and 2423 while fresh and equivalent carbonate-altered gabbro from the sill to the east of the fault are represented by analyses 2416 and 2414. Basal serpentinized dunite and its highly carbonated equivalent are represented by analyses 2420 and 2421.

Insofar as simple comparison of respective chemical analyses is valid, the following observations pertain to Table 18. In the case of the gabbros, the following elements appear to have been lost during carbonate alteration: SiO_2, TiO_2, Al_2O_3, CaO, and Na_2O. Since total iron, and especially MgO seem to have increased in both cases, probably the rocks sampled were not originally the same. For dunites in the southernmost area (Figure 25), $SiO_2$and Al_2O_3 decreased significantly, but total iron, FeO, CaO and K_2O increased during intense carbonate alteration.

Microprobe analyses (Table 19) show that chromite in the basal dunite of the Munro-Beatty sill is similar in composition to chromites in the cumulate base of peridotitic komatiites (Arndt *et al.* 1977). Magnesite formed during carbonate alteration of gabbro (sample 2414) contains 19 molecular percent $FeCO_3$ while magnesite formed during alteration of dunite (sample 2421) contains only 10 molecular percent $FeCO_3$, reflecting the higher iron content of gabbro. Ferroan dolomite with about 7 molecular percent $FeCO_3$ occurs in both carbonate alteration zones.

GEOLOGY, MINERALOGY AND CHEMISTRY OF AREA II

Excellent exposures of komatiitic series volcanic rocks enclosed in pillow basalts, which also host the Munro-Beatty sill, occur about 2.7 km west of the main open pit area at the Munro-Beatty Townships line (Figure 27). Exposed are two areas of gabbro-peridotite. The northernmost of these clearly belongs to a komatiitic flow that terminates in a blunt snout. In the southern area there is limited outcrop and the gabbro-peridotite contact was mapped by Satterly (1952b) as part of the Munro-Beatty sill (sample locations 2601, 2602). Other komatiitic series rocks are massive basalt (sample 2605), and spinifex-bearing pyroxenitic komatiite (sample 2606).

DISCUSSION

Chemical analyses presented in Table 17 and plotted on Figure 26 confirm the komatiitic affinity of the upper part of the Munro-Beatty sill (samples 2601, 2602) as well as the host volcanic rocks that were analysed (samples 2605, 2606).

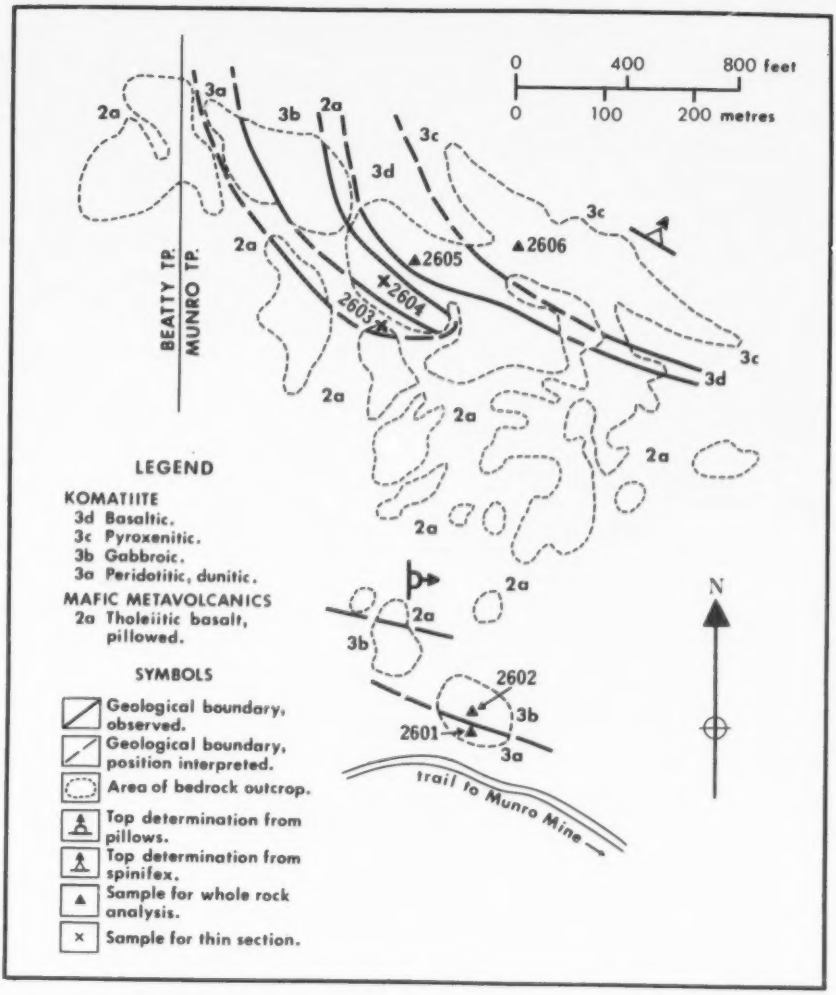


Figure 27. *Geology and sample locations, Munro asbestos deposit, Area II. Geology by U. Kretschmar.*

Geochemistry and Alteration Processes

The komatiitic origin of Archean ultramafic rocks, which as a result of either serpentinization or carbonate-alteration have formed talc, magnesite and asbestos deposits, is demonstrated by field evidence presented above. It remains to briefly examine the chemical evidence which shows the komatiitic composition of the ultramafic rocks and shows the nature of their alteration and attendant loss of constituents.

KOMATIITE GEOCHEMISTRY

The Jensen cation plot (Jensen 1976) has been used extensively throughout this study and has been found to be effective in displaying the continuity of komatiitic flow compositions. The differences between differentiated komatiitic sills and differentiated tholeiitic sills are more effectively shown on the Al_2O_3 vs $FeO^*/(FeO^* + MgO)$ plot of Arndt *et al.* 1977. On Figure 28 are shown all unaltered asbestos-bearing ultramafic sills, as well as analyses of peridotites, pyroxenites and gabbros from the tholeiitic Dundonald sill (Naldrett and Mason 1968). The line dividing the tholeiitic from the komatiite fields is taken from Figure 24 in Arndt *et al.* (1977).

The basal asbestos-bearing dunites and peridotites cannot be distinguished from the tholeiitic Dundonald peridotite. However, the upper gabbroic and pyroxenitic differentiates of the asbestos-bearing sills clearly fall into the komatiitic field. This is taken as further evidence that all the asbestos-bearing sills studied are komatiitic. In the Slade-Forbes deposit, no upper differentiates were found but basaltic komatiite and altered rocks with spinifex chemistry are interbedded with asbestos-hosting peridotite. A single analysis of gabbro from the Munro-Beatty sill falls into the tholeiitic field on Figure 28, although a second analysis of gabbro from the same sill clearly is komatiitic.

In conclusion, the Al_2O_3 vs $FeO^*/(FeO^* + MgO)$ plot appears to effectively distinguish komatiitic from tholeiitic differentiated sills and the data show that all asbestos-bearing differentiated sills studied have komatiitic chemistry.

FIELD RELATIONS

Talc-carbonate alteration of dunitic and peridotitic komatiite flows at the Canadian Magnesite Mines deposit and the Allerston deposit appears to be stratigraphically controlled. While dunitic and peridotitic komatiite flows are completely altered, host basaltic komatiite and calc-alkalic basalt are either much less carbonate-altered or virtually unaltered. Similar stratigraphically controlled carbonate-altered metavolcanics are common throughout the Timmins area and, in the north part of Deloro Township, such rocks constitute the gold-bearing ore horizon of the Delnite, Aunor and Buffalo Ankerite Mines (Fyon and Karvinen 1978).

Discordant carbonate alteration which has equally affected all rocks it traverses is also common, but talc and magnesite-bearing dunitic and peridotitic komatiites at the Canadian Magnesite Mines and Allerston deposits were most likely carbonated on extrusion into a CO_2-rich sea floor or into CO_2-rich seawater, such as may exist on the flanks of vent areas. In both deposits, carbonate-rich iron formation overlies or underlies the altered flow sequences and a syngenetic source of CO_2 is not difficult to envisage. Evidence of the possible seawater origin of this CO_2-bearing fluid is presented below.

Chrysotile asbestos is formed from dunite or peridotite only if the altering fluids have a low CO_2 content (Johannes 1969; Evans 1977). For komatiitic sills to be asbestos-bearing, they must be intruded into a fundamentally different environment than that in which carbonate-altered komatiitic flows occur. This point will be further discussed below, but field evidence that clearly reflects the differing CO_2 contents of the altering fluid is the sequence and mineralogy of veins and the mineralogy of opaques that are found in altered komatiitic ultramafic rocks.

The sequence of veining during alteration of dunite or peridotite is shown in Table 20. In serpentinite, magnetite is finely divided and disseminated throughout the rock and sometimes tends to concentrate interstitially to the olivine pseudomorphs. The magnetite next segregates to form a network of narrow,

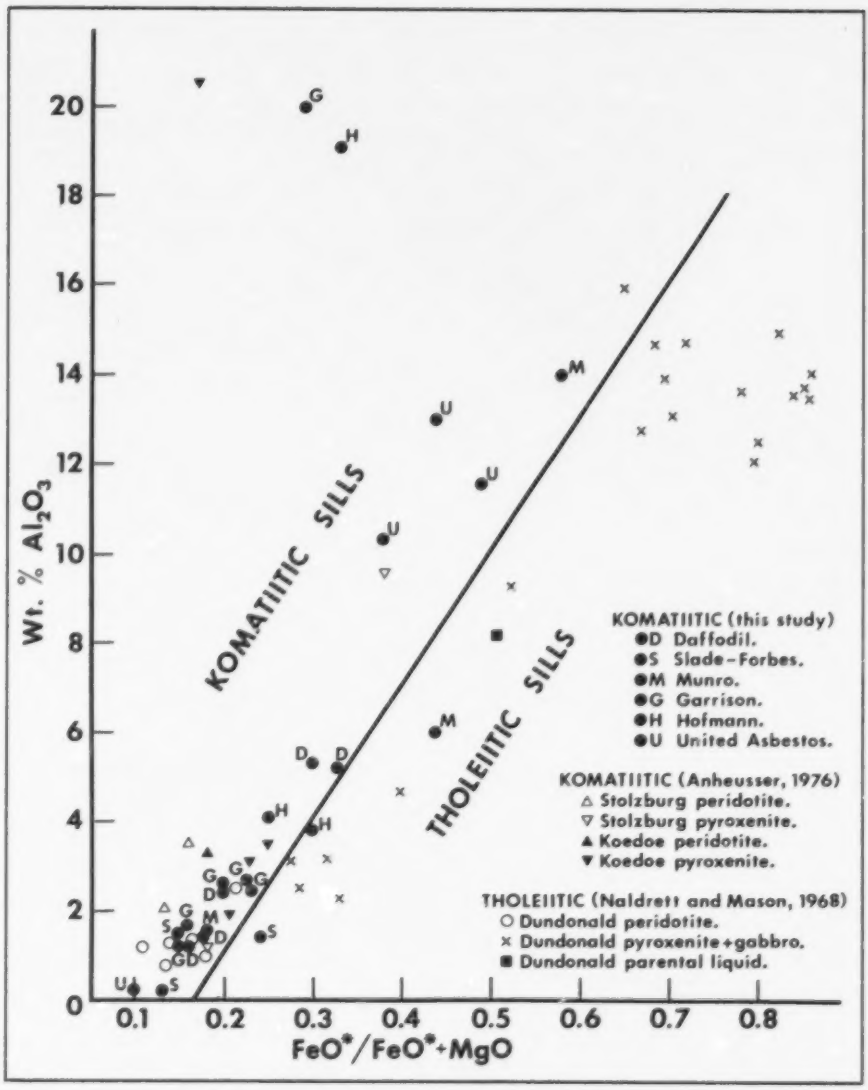


Figure 28. *Al_2O_3 vs FeO*/(FeO* + MgO) plot of asbestos-bearing differentiated sills and Dundonald tholeiitic sill.*

TABLE 20. SEQUENCE OF VEINING DURING PROGRESSIVE ALTERATION OF DUNITE OR PERIDOTITE.

Rock Type	Veins	Opaques
dunite	magnetite	magnetite, chromite
serpentinite	magnetite, asbestos	magnetite
talc-magnesite	carbonate, talc	magnetite, hematite
magnesite-talc	quartz, carbonate	hematite, rutile

coalescing veinlets as at the Garrison asbestos deposit. The magnetite may form separate ladder veinlets or a complex, dense network in a section parallel to the main direction of veining.

Magnetite veins also formed in open channelways at the Daffodil asbestos deposit. At the Munro asbestos deposit, chrysotile veins commonly have magnetite cores. Therefore magnetite is highly mobile during the alteration stages from serpentinization to asbestos formation. As alteration continues, and if the alteration takes place under higher P_{CO2} content, the mineralogy of both the ultramafic rock and veins change. At the Allerston deposit, veins are predominantly carbonate with some talc and hematite. At more advanced stages of alteration, as at the Canadian Magnesite Mines deposit, quartz veins predominate and hematite and rutile are the predominant oxides.

The physical conditions during the formation of asbestos, talc and magnesite are examined in some detail below so that ultramafic rock hydration and/or carbonate alteration may be better understood.

SERPENTINIZATION AND ASBESTOS FORMATION

Serpentinization, asbestos formation and low temperature alteration of ultramafic rocks have been extensively studied and good reviews are presented by Coleman and Keith (1971), Moody (1976) and Nesbitt and Bricker (1978).

The term serpentine is used here as the family name of the three major minerals (lizardite, chrysotile, antigorite) or as a general term when the individual mineralogy is not known or specified. Details of the complex mineralogy of serpentine minerals and of serpentinization from a mineralogical viewpoint are presented by Wicks and Whittaker (1977).

In general, rocks consisting predominantly of olivine and minor pyroxene form serpentinite by hydration at low temperatures (<400°C) and low P_{CO2} or reducing conditions. Serpentinization may, under different conditions, occur both at constant volume or at constant bulk composition.

In individual cases of serpentinization, the process of constant volume or composition may operate at different stages of alteration or one or the other may predominate. The important factors besides mineralogy and paragenesis in elucidating the different possibilities are: (1) time of serpentinization, which may be before, during or after emplacement of the ultramafic body into the crust; (2) the structural and tectonic relationship of the ultramafic body to its country rock; and (3) the duration and magnitude of fluid access to the rock (Moody 1976).

Generally a specific combination of faulting, shearing, serpentinization and metamorphism is considered essential for the formation of chrysotile asbestos (e.g. Grubb 1962; Riordon 1955; Gabrielse 1960). Wicks (1978, 1979) considered two separate environments that result in the formation of chrysotile asbestos. The prograde, metamorphic environment will not be discussed here. The retrograde environment is characterized by pseudomorphic serpentine textures after olivine and pyroxene and results when a high temperature cumulate assemblage cools to a low temperature hydrous assemblage consisting essentially of serpentine and magnetite. Details of the pseudomorphic textures produced have been presented by Wicks and Whittaker (1977). Under prograde conditions, magnetite is usually produced by the serpentinization of olivine but rarely by the other silicates. During

the early stages the magnetite is fine-grained and dispersed through the rock giving it a black, grey or brown colour. With advanced serpentinization, the magnetite migrates to form coarse aggregates and the rock becomes green. In the less common case where hematite is produced during serpentinization the rock has a red colour.

Wicks (1978) described the conditions required to produce chrysotile asbestos:

> "Retrograde serpentinization often produces a minor amount of chrysotile asbestos, but the most abundant type of vein is massive, sometimes apple-green serpentine which is a mixture of lizardite and non-fibrous chrysotile. None of the known asbestos deposits occur in this type of serpentinized ultramafic rock. Chrysotile asbestos deposits develop in a limited niche in the prograde regime below the field of antigorite stability. If metamorphism is too intense, only antigorite will form. If there is no metamorphism, only minor amounts of chrysotile asbestos will form. Thus, a mild metamorphism, coupled with faulting, fracturing, shearing or folding is required to produce asbestos deposits."

Contrary to this generally accepted model of asbestos genesis, our findings show that metamorphism, shearing and faulting seem to have played a minor role. Folding — to which Anhaeusser (1976) assigned a genetic role — has occurred in all deposits studied, since they are steeply dipping, but we do not consider this to have genetic import. A model of asbestos formation in komatiitic sills based on our field observations is presented below (see "Conclusions").

Stable isotope geochemistry has been used to deduce the temperature of serpentinization and to provide evidence on the origin of the serpentinizing fluid. Lizardite-chrysotile serpentinites probably formed at temperatures not greater than 200°C and such serpentinization most probably is caused by waters of meteoric-hydrothermal origin or by sedimentary formation waters which contain a major meteoric water component (Moody 1976).

TALC AND MAGNESITE FORMATION

Talc and magnesite are common secondary alteration minerals of ultramafic rocks, where they may form a marginal envelope or occur adjacent to cross-cutting faults. A description of talc-carbonate altered komatiites is provided by Naldrett (1966). He concluded that bulk chemical changes involved in the talc-carbonate alteration have been additions of CO_2 and removal of H_2O. Little or no Mg, Si, Fe or Ni metasomatism has occurred. Notably, the carbonated Langmuir serpentinites studied by Naldrett contained only between 1 and 9 weight percent CO_2, which is signficantly less than for example the Canadian Magnesite Mines dunitic komatiite (see Table 1).

The environment in which komatiite alters to talc-magnesite rocks is characterized by low total pressure, since komatiites are extruded onto the sea floor, and apparently high CO_2 fluid compositions. The relevant $MgO - SiO_2 - H_2O-CO_2$ system has been studied by Johannes (1969). Phase relations show that the formation of talc-magnesite is strongly pressure dependent and at 500 bars, the lowest pressure studied, talc + magnesite can form from forsterite at about 450°C over a wide range of CO_2 contents (between 20 and 80 molecular percent CO_2). At lower CO_2 contents forsterite can form serpentine and magnesite. At a total pressure of 2 kbars, the equilibrium temperature of this reaction rises with increasing CO_2 contents of the fluid phase from about 380°C at 0.5 molecular percent CO_2 to 490°C at 6 molecular percent CO_2. At lower total pressure, serpentine + magnesite will form at about 350°C. Quartz is stable over a wide range of temperature, pressure and fluid phase compositions in this system. For instance, the breakdown of serpentine to quartz + magnesite can occur at less than 250°C with about 1 molecular percent CO_2 in the fluid phase.

A model for talc and magnesite formation, from komatiitic magma extruded into a carbonate-rich sea bottom environment, and compatible with known phase relations, is presented below (see "Conclusions").

BULK CHEMISTRY AND LOSS OF CONSTITUENTS

Ideally, whole-rock analyses can provide partial answers to two important questions: (1) does talc-magnesite altered dunite belong to the komatiitic or tholeiitic magma series? and (2) to what extent has loss of major constituents occurred during carbonate alteration? The first of these questions has been discussed above and in the sections dealing with individual ore deposits. All carbonate-altered rocks from the Canadian Magnesite Mines and Allerston deposits clearly fall in the komatiite field on Jensen cation plots. These rocks also fall into the komatiite field on plots of TiO_2 vs SiO_2 and Al_2O_3 vs $FeO^*/(FeO^* + MgO)$, which were used by Arndt *et al.* (1977).

A detailed answer to the second question is beyond the scope of this study but plots of the most highly altered dunitic and peridotitic komatiite from Allerston and Canadian Magnesite Mines deposits show that the TiO_2 contents of these rocks are much lower than the Munro Township peridotitic komatiites of Arndt *et al.* (1977). To some extent this is due to the higher MgO content of the dunite, of which no equivalents exist in the area studied by Arndt, but minor TiO_2 loss probably has occurred.

TiO_2 loss during talc-magnesite alteration at the Allerston deposit (North Zone bulk samples, Table 8) also seems to be greater than can be accounted for by simple dilution of dunite with an average 4200 ppm TiO_2 by CO_2. Similar plots for Cr and Ni show less correlation.

From Table 8, nickel values in talc-magnesite from the North Zone, Allerston talc deposit, are on the order of 240 ppm and are much higher in the unaltered peridotite (about 1250 ppm) with similar MgO contents. Ni loss on carbonate alteration therefore seems to have been on the order of 1000 ppm.

Tentative conclusions based on our chemical data are that dunite and peridotite at both the Allerston and Canadian Magnesite Mines deposits have lost TiO_2 but more importantly, Ni. Such a major loss of Ni might be reflected in the host rocks, but the Ni content of iron formation immediately overlying the Canadian Magnesite Mines deposit is low (maximum 430 ppm, Table 5). TiO_2 ranges from 0.34 to 0.52 weight percent, also not unusually elevated. This confirms that if there was loss of these constituents during carbonate alteration, the altering environment was an open system such as the sea bottom and that the leached elements were not precipitated locally but were flushed from the immediate vicinity by sea bottom currents.

OPAQUE MINERALS AND MAGNESITE COMPOSITIONS

Hematite occurs at both the Allerston and Canadian Magnesite Mines deposits and seems to be characteristic of the late and intense carbonate alteration stages. At the Allerston deposit hematite is manifested "... as a reddish tinge in magnesite in drill core but is not noted on surface samples. Magnetite and specular hematite occur as dustings on and interstitially with magnesite as well as individual grains in the talc-matrix" (Bowen *et al.* 1976, p. 26).

At the Canadian Magnesite Mines deposit hematite occurs similarly, but is more frequently seen on the surface. There is a decrease in amount of opaque minerals from early alteration stages to rock type II (highly altered dunitic komatiite: 70 percent magnesite, 16 percent talc, see Table 6). As well, magnetite and chromite are common in rock types III and IV (see "Mineralogy and Chemistry" under "Canadian Magnesite Mines Deposit") but these give way to predominantly hematite and rutile in rock types I and II (Tables 1, 6).

Chromites in spinifex and cumulate zones of komatiitic flows in Munro Township have MgO in the range of 3.8 to 14.3 weight percent and Cr_2O_3 from 39.5 to 56.2 weight percent (Arndt *et al.* 1977). Chromites in sample 2123 (type IV serpentinite) have a similar range of compositions, although analysis number 34 (see Table 3) shows only 1.54 percent MgO.

The $FeCO_3$ content of magnesite is lower in the more altered rock type II than in rock type I, according to Griffis (1970), (8 molecular percent $FeCO_3$ vs 11

TABLE 21. CARBON AND OXYGEN ISOTOPE COMPOSITIONS.

Sample No. and Location	Reaction Time (days)	$\delta^{18}O_{PDB}$	$\delta^{18}O_{SMOW}$	$\delta^{13}C_{PDB}$
Allerston Talc				
2006	14	−14.95	15.45	−1.03
	49	not enough gas		
2008	14	−15.07	15.33	−0.28
	49	−17.67	12.65	−0.26
2012	7	−17.43	12.90	0.30
	49	−17.61	12.71	−0.37
Canadian Magnesite Mines				
2100	14	−17.03	13.31	−3.76
	49	−19.30	10.97	−3.98
2102	14	−16.72	13.63	−3.67
	49	−19.31	10.96	−3.71
2108	14	−16.31	14.05	−2.52
	49	−18.56	11.74	−2.70
2111	14	−16.49	13.87	−3.24
	49	−19.07	11.21	−3.44
Slade−Forbes Asbestos				
2200	14	−16.89	13.45	−1.67
	49	−19.19	11.08	−1.68
Daffodil Asbestos				
2313	14	−5.58	25.11	−11.89
	49	−10.63	19.91	−14.27
GCS Standard	14	−12.91	17.56	0.70

*Analyses from Geoisotope Laboratory, McMaster University.

molecular percent $FeCO_3$, see Table 6). Microprobe analyses of magnesite are only available for rock type I (samples 2103, 2104, 2115, Table 4) and these show that magnesite may contain from less than 1 to about 10.5 molecular percent $FeCO_3$. $FeCO_3$ content is variable, generally low and some grains are zoned. Magnesite in quartz-magnesite-hematite-rutile veins in the most intensely altered area, near the pit (see Figure 5) contains about 4 molecular percent $FeCO_3$ (sample 2130, Table 4).

CARBON AND OXYGEN ISOTOPE DATA

Carbon and oxygen isotope analyses for magnesites from the Canadian Magnesite Mines, Allerston, and Slade-Forbes deposits are presented in Table 21 and Figure 29. Details of the analytical techniques used are presented in Appendix B. Oxygen isotopic values are relatively constant for all deposits at about $\delta^{18}O_{SMOW} = +12‰$ while carbon isotopic values range from $\delta^{13}C_{PDB} = -4‰$ to 0. Sample 2313 is not shown on Figure 29 because it is a weathered sample of dunite that has exchanged oxygen with modern meteoric water. The remaining values are closely similar to those obtained by Fyon *et al.* (1980) for cherty replacement dolomites in altered metavolcanics and komatiite flows in Deloro and Tisdale Townships. The reader is referred to their work for details of the interpretation of oxygen and carbon isotopic values.

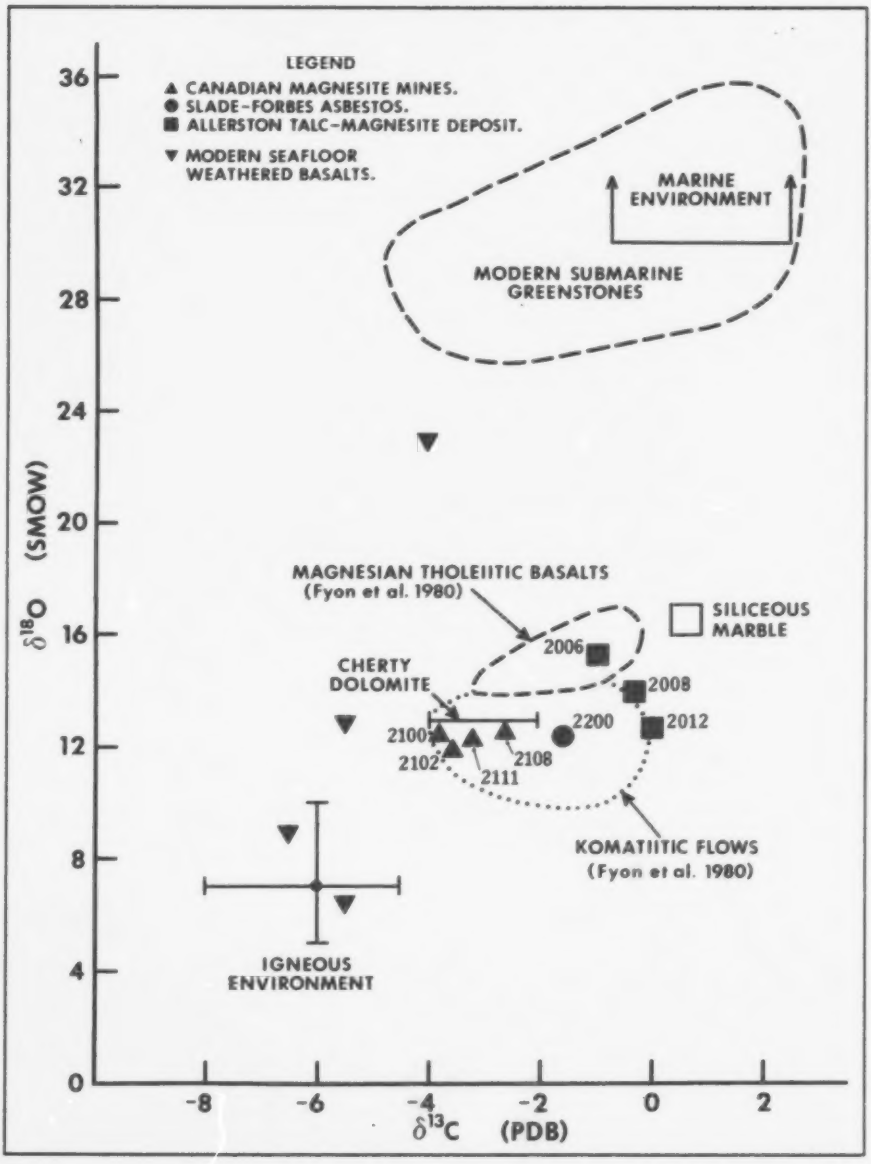


Figure 29. *Carbon and oxygen isotopic compositions of samples from Canadian Magnesite Mines deposit, Slade-Forbes deposit, and Allerston deposit, in comparison with modern seafloor basalts.*

COMPOSITION AND SOURCE OF FLUID AND TIMING OF ALTERATION

Progressive changes in mineralogy, bulk chemistry and vein composition clearly suggest that the later alteration stages were produced by oxidizing fluids high in CO_2 but that initially, the fluids seem to have had low P_{CO2}. The sequence of replacement or pseudomorphing of earlier minerals by later minerals is approximately: olivine, serpentine, chlorite, talc, magnesite. Generally, not all stages are preserved. The changes appear to be the result of progressive carbonation in the case of the Allerston and Canadian Magnesite Mines deposits. In both deposits neither olivine nor serpentine is preserved.

On the other hand, carbonation occurred later than serpentinization and asbestos formation at the Munro asbestos deposit. Carbonate alteration is cross-cutting and clearly occurred later than formation of asbestos (see Figure 25) and perhaps is related to intrusion of the diabase dike at the east end of the property.

Parallel zones of talc-carbonate and chrysotile-bearing serpentinite at the Slade-Forbes asbestos deposit suggest that initial bulk composition of the ultramafic rock plays an important role in determining the alteration mineralogy and that carbonation is not necessarily later. Further evidence for the importance of bulk composition is that the North talc-magnesite zone at the Allerston deposit is overlain and underlain by talc-chlorite rock which probably is a less altered peridotitic chilled margin of the dunitic lens that forms the main talc-magnesite zone.

The altering fluid was mainly seawater with a minor igneous component as shown by the isotopic data. Concordant carbonatized komatiites probably reflect alteration on the flanks of volcanic vents where CO_2-rich solutions may have originated. Decomposition of sea bottom carbonate or dissolution of organic carbonate are an unlikely source for CO_2 since such reactions would generate fluids having very negative $\delta^{13}C$ values (as low as $-28‰$; Fyon *et al.* 1980).

Conclusions

All talc, magnesite and asbestos deposits examined in this study have been derived from magmas of komatiitic composition and, therefore, these deposits form a distinct class of industrial mineral deposits. Intrusive komatiitic magma with a high initial olivine content may have formed differentiated sills with thick basal olivine concentrations and relatively thin upper, iron-rich differentiates. Serpentinization and chrysotile-asbestos formation occurred in thick dunitic to peridotitic basal units of such sills, during their slow cooling in an undisturbed tectonic environment. The cooling sill absorbed the water necessary for serpentine and asbestos formation from the seawater-saturated host rocks. The role of later faulting, folding, shearing and metamorphism in the formation of these types of Archean asbestos deposits was minor and does not appear to have genetic significance. Commercial Archean asbestos deposits are common and there are several past or potential producers in the Timmins-Kirkland Lake area. The potential for more occurrences is also good.

Extrusive olivine-rich komatiite altered progressively to either talc or magnesite-rich rocks on the sea floor, probably on the flanks of volcanic vents that provided a source of CO_2. There is only one operating talc mine (Steetley Talc Limited, Penhorwood Township) and one potential producer (Allerston talc deposit) known in the area covered by this study but the potential for other similar occurrences is good.

Canadian Magnesite Mines Limited's deposit is the only known potential source of magnesia, but unless an inexpensive method can be found to obtain a more iron-free MgO product than is possible with current technology, there is limited economic potential for the type of Archean komatiitic magnesite deposit exemplified by the Canadian Magnesite Mines deposit.

Guidelines for Exploration

1. In a regional sense, Archean komatiitic talc, magnesite and asbestos deposits should be sought in the basal mafic and ultramafic cycles of 'greenstone' belts, wherever komatiites are found. In the Timmins area, komatiites do not occur in a restricted stratigraphic interval. In the Matheson area, komatiites occur in the Munro Group, and in Midlothian Township, komatiites occur in the basal strata of the Halliday dome.
2. Archean komatiitic talc and magnesite deposits occur either in a proximal volcanic environment or may be interstratified with carbonate iron formation in a more distal environment. In a regional sense, such deposits should be sought where carbonate alteration of the volcanic pile is widespread, as for instance in the Timmins gold camp.
3. Archean komatiitic asbestos deposits occur similarly to Archean talc and magnesite deposits, but in a carbonate-free environment. The deposits occur in olivine-rich basal portions of differentiated sills or flows. The thicker, more magnesian and less differentiated the basal accumulation is, the more likely it is that asbestos will develop and in all likelihood, the larger will be the tonnage of fibre.

Appendix A — Electron Microprobe Analyses

SAMPLES 2412, 2414, 2421
ADDITIONAL DATA AND COMMENTS
by Claudio Cermignani

ANALYTICAL CONDITIONS

All analyses were performed at 20 KV accelerating voltage, and approximately 20 nA sample current.

100 second (live time) spectra were used for all opaque and silicate phases.

50 second (live time) spectra were used for all carbonates.

Data reduction was done with a modified version of the program PESTRIP, developed by P.J. Statham, at the University of Cambridge, England.

Accuracy was evaluated by reference to analyses of standards.

Precision is expressed as a percentage, and was calculated on the basis of counting statistics. It is a minimum estimate, but close to the actual precision.

RESULTS

SAMPLE 2412

Spinel. Fe^{2+} and Fe^{3+} contents were calculated from structural considerations (program RECALC, by J.C. Rucklidge). Seven out of eight analyses suggest a rather uniform composition and grain homogeneity, with minor variations in the Fe/Mg ratio. The remaining analysis is characterized by a lower Cr/Fe ratio. Accuracy: see chromite, hematite and ilmenite standards.

Precision (percent):

Al	0.6
Cr	0.4
Fe	0.4
Mg	1.1
Mn	4.8
Ti	2.9

Pyrite. Co content is 1-2 percent. Analysis confirms proper stripping of Fe Kbeta line, i.e. Co is real. Accuracy for Co is 1-2 percent on a pure Co standard. Precision for Co is 1.9 percent

Chalcopyrite. Has little Co, no Ni

Pyrrhotite. Little Co and Ni

Serpentine occurs both with needle and stubby morphologies. The Fe content is unusually high. No Ni was detected.

SAMPLE 2414.

"Aspy" is Co, Fe bearing gersdorffite (NiAsS), with Fe content approximately constant, and Ni/Co varying between 10.3 and 1.0 (based on two analyses).

Accuracy: proper "stripping" of Co Kbeta has been verified, i.e. Ni values are unbiased. See also FeNiS and arsenopyrite standards. See also sample 2412, pyrite, for Co. Precision: see see sample 2421.

Chalcopyrite.

Pyrite.

TiO_2 is finely intergrown with quartz.

Carbonates. Analyses are of microareas (m.a.) in coarser grains and of "points" (p.a.) or "almost points" (a.p.a.) in the finer ones. In the latter, spurious contents from adjoining grains are difficult to avoid (for example, Si from quartz). (A) Magnesite-siderite solid solution, with minor Mn and Ca. Mg/Fe ratio is between 2.8 and 2.2 (8 analyses). Relatively coarse grained in carbonate "eyes", and also fine grained. (B) Ferroan dolomite, with little Mn. Fine grained. Accuracy: see dolomite, rhodonite and fayalite standards.

Precision (percent):

	(A)	(B)
Ca		0.5
Mg	0.7	1.0
Fe	0.8	1.5
Mn	8.1	6.6

SAMPLE 2421

"Aspy". See 2414. Ni/Co between 7.9 and 0.7 (three analyses). Accuracy: see 2414. Precision (percent) in high Ni/Co grain:

Ni	0.4
Co	1.2
Fe	1.4
Cu	4.7
As	0.4
S	0.4

Pyrite.

Chalcopyrite has trace Co.

Spinel. Similar to spinels in 2412.

Carbonates. All analyses are "point" analyses. (A) Ferroan magnesite (breunnerite). (B) As in 2414.

Appendix B — Analytical Methods for Determining Oxygen and Carbon Isotopic Values

Samples of total rock, crushed to −200 mesh, were reacted with phosphoric acid at 50°C in sealed glass tubes for either 14 or 49 days. The CO_2 liberated was analysed on a Nier-type mass spectrometer. The raw data have been converted to analyses with respect to the SMOW and PDB standards, assuming that the reaction was between calcite and phosphoric acid at 25°C. This assumption has virtually no effect on the carbon isotopic values (shifting them by less than 0.1 percent).

Appendix C — XRD and Staining Methods for Talc and Magnesite Determination

Ideally, a rapid method of identifying talc and magnesite and determining their proportion in a rock would aid in exploring for talc and magnesite deposits. Our preliminary results are presented below.

X–RAY DIFFRACTION

Whole rock powders were scanned using the following conditions: 40 kv, 20 ma, T.C. = 2, chart speed = 2 cm/sec, goniometer speed is about $2^{\circ}\ \theta$/min.

Magnesite can readily be distinguished from dolomite or calcite since there is no overlap of major peaks. A determinative curve for quantitative determination could readily be constructed by making up a series of standards.

Matrix effects and preferred orientation of grains are severe with talc and the sample must be irradiated in a cup or the sample powders must be compressed. Qualitative estimates from relative peak heights show about 1 percent talc in sample 2111, 15 percent talc in 2108 and 20 percent talc in 2102. These values correlate well with the petrographic description of the samples (see Table 2).

STAINING

Magnesite can be identified in hand specimen by staining a cut surface, impregnated with parafin to reduce porosity, with Titan Yellow stain, in a 5 percent caustic soda solution. The magnesite will turn yellow after about 5 minutes (J. LeAnderson, unpublished Staining Manual, Department of Geology, Queen's University, 1973).

Another method is described by Reid (1969) and consists of etching the cut rock surface with hot dilute HCl for 30 seconds to 1 minute. The etched surface is then stained with Alizarin Red S solution which causes magnesite to turn purple.

CONCLUSIONS

Rapid methods for determination of talc and magnesite can probably be developed, but are beyond the scope of this study. As well, unless the high iron content of komatiitic magnesite can be reduced, such magnesite is not worth exploring for.

References

Anhaeusser, C.R.
1976: The Nature of Chrysotile Asbestos Occurrences in Southern Africa, A Review; Economic Geology, volume 71, p.96-116.

Arndt, N.T.
1975: Ultramafic Rocks of Munro Township and their Volcanic Setting; Unpublished Ph.D. thesis, University of Toronto, 192p.
1976: Ultramafic Rocks of Munro Township: Economic and Tectonic Implications; p.617-657 *in* Metallogeny and Plate Tectonics, edited by D.F. Strong, Geological Association of Canada, Special Paper No. 14.

Arndt, N.T., Francis, D., and Hynes, A.
1979: The Field Characteristics and Petrology of Archean and Proterozoic Komatiites; Canadian Mineralogist, volume 17, p. 147-163.

Arndt, N.T., Naldrett, A.J., and Pyke, D.R.
1977: Komatiitic and Iron-rich Lavas of Munro Township, Northeast Ontario; Journal of Petrology, volume 18, p.319-369.

Bowen, R.P., Middleton, R.S., Fisher, T., and Winters, J.
1976: Geological Report on the Allerston Property, Whitney Township; unpublished report by Rosario Resources Corp. for Ontario Division of Mines, available at Resident Geologist's office, Ontario Ministry of Natural Resources, Timmins, Ontario.

Bright, E.G.
1970: Geology of Halliday and Midlothian Townships; Ontario Department of Mines, Geological Report 79.

Canadian Mining Journal
1981: Other Industrial Minerals; Canadian Mining Journal, February 1981, p.142.

Carlson, H.D.
1967: Deloro Township, District of Cochrane; Ontario Department of Mines, Preliminary Map P.342, scale 1 inch to 1/4 mile.

Clarke, G.M.
1979: Talc, Destiny and Diversity; Industrial Minerals, No. 144, September 1979, p.23-59.

Coleman, R.G., and Keith, T.E.
1971: A Chemical Study of Serpentinization, Burro Mountain, California; Journal of Petrology, volume 12, p.311-328.

Evans, B.W.
1977: Metamorphism of Alpine Peridotite and Serpentinite; Annual Review, Earth and Planetary Science Letters, volume 5, p.397-447.

Fyon, J.A., and Karvinen, W.C.
1978: Volcanic Environment of Gold Mineralization in the Timmins Area; p.202-205 *in* Summary of Field Work, 1978, by the Ontario Geological Survey, edited by V.G. Milne, O.L. White, R.B. Barlow, and J.A. Robertson, Ontario Geological Survey, Miscellaneous Paper 82.

Fyon, J.A., Schwarcz, H.P., and Crocket, J.H.
1980: Carbon and Oxygen Isotope Chemistry of Replacement Carbonates from the Timmins-Porcupine Gold Camp; p.72-83 *in* Summary of Research, Geoscience Research Grant Program, Ontario Geological Survey, Miscellaneous Paper 93.

Gabrielse, H.
1960: The Genesis of Chrysotile Asbestos in the Cassiar Asbestos Deposit, Northern British Columbia; Economic Geology, volume 55, p.327-337.

Goodwin, A.M., and Ridler, R.H.
1969: The Abitibi Orogenic Belt; *in* Symposium on Basins and Geosynclines of the Canadian Shield, edited by A.J. Baer, Geological Survey of Canada, Paper 70-90.

Griffis, R.J.
1970: Genesis of the Deloro Township Talc-Magnesite Deposit, Ontario, Canada; unpublished M.Sc. thesis, Washington State University.
1972: Genesis of a Magnesite Deposit, Deloro Township, Ontario; Economic Geology, volume 67, p.63-71.

Griffis, A.T.
(in press): Canadian Magnesite Mines Limited, *in* The Geology of Canadian Industrial Mineral Deposits, Canadian Institute of Mining and Metallurgy.

Grubb, P.C.
1962: Serpentinization and Chrysotile Formation in the Matheson Ultrabasic Belt, Northern Ontario; Economic Geology, volume 57, p.1228-1246.

Hendry, N.W.
1951: Chrysotile Asbestos in Munro and Beatty Townships, Ontario; Transactions of the Canadian Institute of Mining and Metallurgy, volume 54, p.28-35.

Hewitt, D.F.
1950: Asbestos in Ontario; Ontario Department of Mines, Industrial Minerals Circular No. 1.
1972: Talc in Ontario; Ontario Department of Mines and Northern Affairs, Industrial Mineral Report 40.

Hewitt, D.F. and Satterly, J.
1953: Asbestos in Ontario; Ontario Department of Mines, Industrial Mineral Circular No. 1, 23p.

Industrial Minerals
1971: The Potential of Canadian Magnesite Mines Limited; Industrial Minerals, April 1971, p.40-43.

Jensen, L.S.
1976: A New Cation Plot for Classifying Subalkalic Volcanic Rocks; Ontario Divsion of Mines, Miscellaneous Paper 66, 22p.
1980: Kirkland Lake-Larder Lake Synoptic Mapping Project, Districts of Cochrane and Timiskaming; p.55-60 *in* Summary of Field Work 1980, by the Ontario Geological Survey, edited by V.G. Milne, O.L. White, R.B. Barlow, J.A. Robertson and A.C. Colvine, Ontario Geological Survey, Miscellaneous Paper 96.

Johannes, W.
1969: An Experimental Investigation of the System $MgO-SiO_2-H_2O-CO_2$; American Journal of Science, volume 267, p.1083-1104.

Jolly, W.T.
1978: Metamorphic History of the Archean Abitibi Belt; p.63-78 *in* Metamorphism of the Canadian Shield, Geological Survey of Canada, Paper 78-10.

Kretschmar, U., and Kretschmar, D.
1975: Geology and Ultramafic flows of the Malartic Group N.W. Quebec; Geological Society of America, Program, Abstracts, volume 7, p.801.
1979: Talc-Magnesite and Asbestos Deposits of the Timmins-Kirkland Lake Area; p.13 *in* Geoscience Research Seminar, Abstracts, edited by E.G. Pye, Ontario Geological Survey.
1980: Progress Report: Talc, Magnesite and Asbestos Deposits in the Kirkland Lake, Timmins Area; Ontario Geological Survey, Open File Report 5310.

Longley, C.S.
1944: Deloro Section, Porcupine Southgate; Unpublished Geological Map, Resident Geologist's files, Ontario Ministry of Natural Resources, Timmins, Ontario.

Marshall, H.I.
1947: Geology of Midlothian Township; Ontario Department of Mines, Annual Report, volume 56, part 5, p.1-24

Moody, J.B.
1976: Serpentinization, a Review; Lithos, volume 9, p. 125-138

Naldrett, A.J.
1966: Talc-Carbonate Alteration of some Serpentinized Ultramafic Rocks South of Timmins; Journal of Petrology, volume 7, p.489-499.

Naldrett, A.J., and Mason, G.D.
1968: Contrasting Archean Ultramafic Igneous Bodies in Dundonald and Clergue Townships, Ontario; Canadian Journal of Earth Sciences, volume 5, p.111-143.

Naldrett, A.J., and Turner, A.R.
1977: The Geology and Petrogenesis of a Greenstone Belt and Related Nickel Sulphide Mineralization at Yakabindie, Western Australia; Precambrian Research, volume 5, p.43-103.

Naldrett, A.J., and Smith, I.E.M.
(in press): Mafic and Ultramafic Volcanism during the Archean; Proceedings of the Komatiite Symposium, Penrose Conference.

Nesbitt, H.W., and Bricker, O.P.
1978: Low Temperature Alteration Processes affecting Ultramafic Bodies; Geochemica and Cosmochemica Acta, volume 42, p.403-409.

Nesbitt, R.W., Sun, S.S., and Purvis, A.C.
1979: Komatiites: Geochemistry and Genesis; Canadian Mineralogist, volume 17, p.165-186.

Pearse, G.H.K.
1977: Talc, Soapstone and Pyrophyllite; Canada Minerals Yearbook 1977, Chapter 49.

Ploeger, F. and Grabowski, G.
1979: Garrison Township, District of Cochrane; Ontario Geological Survey, Preliminary Map P.868, Kirkland Lake Data Series.

Pyke, D.R.
1974: Timmins Area, District of Timiskaming and Cochrane; Ontario Division of Mines, Preliminary Map P.941.
1980: Geology of the Timmins Area, District of Cochrane; Ontario Geological Survey, Open File 5281.

Pyke, D.R., Naldrett, A.J., and Eckstrand, C.R.
1973: Archean Ultramafic Flows, in Munro Township; Geological Society of America, Bulletin, volume 84, p.955-978.

Reid, W.P.
1969: Mineral Staining Tests; Mineral Industries Bulletin, Colorado School of Mines Research Foundation, volume 12, No. 3, p.1-30.

Riordon, P.H.
1955: The Genesis of Asbestos in Ultrabasic Rocks; Economic Geology, volume 50, p.67-81.

Ross, J.G.
1931: Chrysotile Asbestos in Canada; Canada Department of Mines, Mines Branch Publication No. 707

Satterly, J.
1949: Geology of Garrison Township, District of Cochrane; Ontario Department of Mines, Annual Report for 1949, Volume 58, Part 4.
1952a: Geology of Harker Township, Ontario Department of Mines, Annual Report for 1951, Volume 60, Part 7.
1952b: Geology of Munro Township, Ontario Department of Mines, Annual Report for 1951, Volume 60, Part 8.

Spence, H.S.
1940: Talc, Steatite and Soapstone; Canada Department of Mines and Resources, Mines Geology Branch, Bureau of Mines, Publication No. 803.

Spooner, E.T.C.
1978: Industrial Minerals and Rocks, *in* Unpublished Notes for Ore Deposits Workshop, University of Toronto, December 1978.

Svikis, V.D.
1968: Dead-burned Magnesia from Ontario Magnesite Concentrate; Canada Department of Energy, Mines and Resources, Mines Branch, Mineral Processing Division, Internal Report MP 1-68-7

Vagt, G.O.
1976: Asbestos; Canada Department of Energy, Mines and Resources, Mineral Policy Series, MR 155.
1981: Asbestos; Canadian Mining Journal, volume 102, No. 2, p.129.

Vos, M.A.
1971: Asbestos in Ontario; Ontario Department of Mines, Industrial Minerals Report 36.

Wicks, F.J.
1978: Asbestos Deposits; *in* Unpublished Notes for Ore Deposits Workshop, University of Toronto, December 1978.
1979: Mineralogy, Chemistry and Crystallography of Chrysotile Asbestos; *in* Short Course in Mineralogical Techniques of Asbestos Determination, edited by R.L. Ledoux, Mineralogical Association of Canada, Short Course Handbook, Volume 4, May 1979.

Wicks, F.J., and Whittaker, E.J.W.
1977: Serpentine Textures and Serpentinization; Canadian Mineralogist, volume 15, p.459-488.

Winson, R.W.
1976: Asbestos; *in* Industrial Minerals and Rocks, 4th edition, American Institute of Mining, Metallurgical and Petroleum Engineers, Inc. New York.

Index

Abitibi Belt 53
Al_2O_3 vs FeO*/(FeO* + MgO) plot 70,74
  Dundonald tholeiitic sill 71
  Sills, asbestos-bearing differentiated 71
Allerston, Ralph 22
Allerston talc-magnesite deposit 4,22-35,72,74,77,78
  Carbon & oxygen isotope data 75,76
  Cross-section 24
  Economic geology 23
  Geology 23-26
  Map
    Claim map 22
    Location 2,6,8
  Mineralogy & chemistry 26-35
    Chemical analyses 28-31
    Jensen cation plot 34
    Mineralogy 35
    Modal Analyses 26-27,34,35
    Normative compositions 28-31
  Stratigraphic position 7
  Talc-carbonate alteration 70
Amygdules
  Dacite 49
Analyses, chemical
  Allerston talc-magnesite deposit 28-31
  Canadian Magnesite Mines Ltd. 14
  Daffodil asbestos deposit 40
  Garrison asbestos deposit 58
  Hofmann asbestos deposit 55
  Munro asbestos deposit 64,66
  Munro-Beatty Sill 66
  Slade-Forbes deposit 45
  United Asbestos deposit 50
Analyses, microprobe
  Canadian Magnesite Mines Ltd. 13,20
    Carbonate in magnesite 18,20
    Dacite, calc-alkalic 18
    Dunite, highly carbonated 13,20
    Opaques 17
    Quartz-carbonate vein 18
  Munro asbestos deposit
    Spinel & carbonates 67
Analyses, modal
  Allerston talc-magnesite deposit
    North & South Zones 26-27,34,35
  Canadian Magnesite Mines Ltd. 16,19,35
Analyses, normative compositions
  Allerston talc-magnesite deposit 28-31
  Canadian Magnesite Mines Ltd. 14
  Daffodil asbestos deposit 40
  Garrison asbestos deposit 58
  Hofmann asbestos deposit 55
  Munro asbestos deposit 64
  Slade-Forbes deposit 45
  United Asbestos deposit 50
Andesite, calc-alkalic 7,23,49
  Chemical analyses
    Allerston deposit 31
    Canadian Magnesite Mines Ltd. 14
    United Asbestos deposit 50
  Modal analyses
    Canadian Magnesite Mines Ltd. 16
  Normative composition
    Allerston deposit 31
    Canadian Magnesite Mines Ltd. 14
    United Asbestos deposit 50
Andesitic rock 6,9,12
Antigorite
  Modal analyses 16
Aplitic intrusions
  Allerston deposit 25
Archean industrial minerals
  Asbestos 4-5
  Magnesite 4
  Talc 4
Archean rock
  Timmins area 6-7
Archean ultramafic rocks
  Komatiitic 70
    Talc, magnesite & asbestos 79
Argillite
  Iron formation 25
Asbestos
  Archean 4-5
  Chrysolite vein 25
    Photo 38
  Daffodil asbestos deposit 36-42
  Dunitic polyhedral breccia 42
  Garrison (Bird-Ginn) asbestos deposit 57-59
  Hofmann asbestos deposit 53-56
  Komatiite
    Archean ultramafic rock 70
    Carbonate altered 72
    Differentiated sill 39,70
  Munro asbestos deposit 60-69
  Production 5
  Slade-Forbes asbestos deposit 43-46
  Stratigraphic position
    Midlothian Twp. 47
    Munro, Harker & Garrison Twp. 53
    Timmins area 7
  United Asbestos deposit 47-52
Asbestos, chrysolite 47,48,53,57,61
  Chemical analyses
    United Asbestos deposit 50
  Formation 72-73
    Differentiated sills 78,79

Komatiite
Low CO_2 content 70
Magnetite veins 72
Slade-Forbes deposit 43,46
Timing of alteration 77
Aunor Mine 70
Basalt 6,12
Chemical analyses
Canadian Magnesite Mines Ltd. 14
Daffodil deposit 40
Garrison deposit 58
Slade-Forbes deposit 45
Microprobe analyses of opaques
Canadian Magnesite Mines Ltd. 17
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative compositions
Canadian Magnesite Mines Ltd. 14
Daffodil deposit 40
Garrison deposit 58
Slade-Forbes deposit 45
Basalt, calc-alkalic 7,23,36,39,43
Chemical analyses
Allerston deposit 31
Canadian Magnesite Mines Ltd. 14
Daffodil deposit 40
Slade-Forbes deposit 45
Microprobe analyses of opaques
Canadian Magnesite Mines Ltd. 17
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative compositions
Allerston deposit 31
Canadian Magnesite Mines Ltd. 14
Daffodil deposit 40
Slade-Forbes deposit 45
Pillows 36
Basalt, carbonate-chlorite altered
Chemical analyses
Daffodil deposit 40
Normative compositions
Daffodil deposit 40
Basalt, fragmental
Chemical analyses
Canadian Magnesite Mines Ltd. 14
Microprobe analyses of opaques
Canadian Magnesite Mines Ltd. 17
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative composition
Canadian Magnesite Mines Ltd. 14
Basalt, magnesian 68
Basalt, modern seafloor
Carbon & oxygen isotope data 76
Basalt, tholeiitic 6
Chemical analyses
Canadian Magnesite Mines Ltd. 14
Daffodil deposit 40
Garrison deposit 58
Microprobe analyses of opaques
Canadian Magnesite Mines Ltd. 17
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative compositions
Canadian Magnesite Mines Ltd. 14
Daffodil deposit 40
Garrison deposit 58
Basalt, tholeiitic pillowed 61,68
Chemical analyses
Munro deposit 64
Normative composition
Munro deposit 64
Basaltic komatiite 6,12,36,43,68
Chemical analyses
Allerston deposit 30,31
Canadian Magnesite Mines Ltd. 14
Daffodil deposit 40
Munro deposit 64
Slade-Forbes deposit 45
United Asbestos deposit 50
Microprobe analyses of opaques
Canadian Magnesite Mines Ltd. 17
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative compositions
Allerston deposit 30,31
Canadian Magnesite Mines Ltd. 14
Daffodil deposit 40
Munro deposit 64
Slade-Forbes deposit 45
United Asbestos deposit 50
Basaltic komatiite, carbonated
Chemical analyses
Allerston deposit 31
Normative compositions
Allerston deposit 31
Basaltic rock 9
Chemical analyses
Garrison asbestos deposit 58
Normative analyses
Garrison asbestos deposit 58
Bird, S.J. 57
Bird-Ginn
see Garrison (Bird-Ginn) asbestos deposit
Bray Lake 48

Breccia
Iron formation 25
Breccia, polyhedral texture
Dunitic komatiite 38
Asbestos 42
Photo 38
Buffalo Ankerite Mine 70
Calc-alkaline volcanic rock
Deloro Group 6
Canada Talc Industries Ltd. 4
Canadian Exploration Ltd. 47
Canadian Johns-Manville Co. Ltd.
Garrison asbestos deposit 57
Munro asbestos deposit 60
Steetley Talc Ltd. 4
United Asbestos deposit 47
Canadian Magnesite Mines Ltd. 7-21,72,73,74,77,78,79
Carbon & oxygen isotope data 75,76
Economic geology 9,11
Geology 11-12
Cross-section 10
Photo 12
Magnesite
Archean 4
Stratigraphic position 7
Map
Claim 9
Location 2,6,8
Mineralogy & chemistry 13-20,35
Chemical analyses 14-15
Jensen cation plot 20
Microprobe analyses
Carbonate in magnesite 18
Opaques 17
Modal analyses 16,19,35
Normative minerals 14-15
Trace Element
Iron formation 19
Talc-carbonate alteration 70
Canadian Refractories Ltd. 4
Carbon isotope data 75-76
CaO
Magnesite-talc body 13
Low content 9
Carbonate
Addition to komatiites
Talc-magnesite formation 73
Calc-alkalic basalt or andesite 23
Calc-alkalic dacite 13
Iron formation 25
Magnesite
Microprobe analyses 18
Magnesite-talc rock 72
Microprobe abalyses
Canadian Magnesite Mines Ltd. 18,20
Munro asbestos deposit 67
Modal analyses
Allerston talc-magnesite deposit 26-27,34
Canadian Magnesite Mines Ltd. 16
North Zone Allerston deposit 26
South Zone Allerston deposit 26
Carbonate alteration
Archean ultramafic rocks 70
Calc-alkalic basalt or andesite 23
Dunitic komatiite
Allerston talc-magnesite deposit 35
Canadian Magnesite Mines Ltd. 35
Photo 12
High CO_2 fluid (hydrothermal, meteoric)
Talc-magnesite formation. 12,70,72,73,78
Komatiites 11,12,21
Loss of major constituents 74
Low CO_2 fluid (seawater)
Serpentinization & asbestos formation 70,72,78
Munro asbestos deposit
Munro-Beatty sill 68
Serpentinized dunite 38
Timing of alteration 77
see also Talc-carbonate alteration
Carbonate veins
Dunitic komatiite
talc-magnesite zone 25
Carbonate zone
Ultramafic rock (komatiitic) 7
Chemical analyses
see Analyses, Chemical
Chemistry, bulk 74,77
Chert
Iron formation 25
Chilled margin
Diabase dike 49
see also Differentiation
Chlorite
Dunitic komatiite 25
North Zone Allerston deposit 26
Iron formation 25
Modal analyses
Allerston talc-magnesite deposit 26-27,34,35
Canadian Magnesite Mines Ltd. 16,35
Chloritization
Calc-alkalic basalt or andesite 23
Chromite
Dunite 72
Munro-Beatty sill 68
Peridotitic komatiite 20
Talc-magnesite rock 74
Chrysotile 73
see also Asbestos
Constituents, major
Loss
Dunite & peridotite 74
Construction
Asbestos 4-5
Cumulate texture
Serpentinite 38
Serpentinized dunite 43,57,68

Dacite
Tisdale Group 6,12
Dacite, calc-alkalic
Chemical analyses
Allerston talc-magnesite deposit 31
Canadian Magnesite Mines Ltd. 14
Microprobe analyses
Canadian Magnesite Mines Ltd. 18
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative composition
Allerston talc-magnesite deposit 31
Canadian Magnesite Mines Ltd. 31
Dacite, variolitic 48,49
Dacitic flows
Deloro Group 6
Allerston talc-magnesite deposit 23
Dacitic pyroclastics
Deloro Group 6
Allerston talc-magnesite deposit 7
Daffodil asbestos deposit 36-42,72
Carbon & oxygen isotope data 75
Economic geology 36
Geology 36,38
Photo 38,39
Map
Claim 37
Location 2,6,8
Mineralogy & chemistry 38-42
Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
Chemical analyses 40
Jensen cation plot 42
Normative compositions 40
Stratigraphic position 7
Delnite Mine 70
Deloro Group
Timmins area 6
Allerston talc-magnesite deposit 7,23
Daffodil asbestos deposit 7,
Slade-Forbes asbestos deposit 7
Deloro Twp.
Canadian Magnesite Mines Ltd. 7-21
Daffodil asbestos deposit 36-42
Slade-Forbes asbestos deposit 43-46
Destor-Porcupine Fault 7,53
Diabase
Gabbroic differentiate 49
Diabase dikes
Allerston deposit 25
Slade-Forbes asbestos deposit 43
Diabase dikes, Matachewan 47,49
Diabasic texture
Gabbroic rock 68
Differentiate
Asbestos 57
Asbestos-bearing
Al_2O_3 vs FeO*/(FeO* + MgO) plot 70,71
Lloyd Lake Complex 49
Munro-Beatty sill 61
Olivine-rich (CO_2 free)
Asbestos formation 78,79
Sills 50
Diorite 68
Dioritic rock 54
Chemical analyses
Hofmann asbestos deposit 55
Normative compositions
Hofmann asbestos deposit 55
Dolomite
Microprobe analyses
Munro asbestos deposit 67
Dolomite, ferroan 68
Microprobe analyses
Munro asbestos deposit 67
Dolomite, Grenville
Talc 4
Domal structure
Timmins area 6
see also Shaw Dome
Dominion Gulf Co. 47,53
Dundonald tholeiitic sill 70
Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
Dundonald Twp. 53
Dunite 54,61
Asbestos 36
Bulk chemistry & loss of constituents 74
Carbon & oxygen isotope data 75
Carbonate alteration
High CO_2 (talc-magnesite) 70
Low CO_2 (asbestos) 70
Chemical analyses
Allerston talc-magnesite deposit 28
Daffodil deposit 40
Garrison asbestos deposit 58
Munro asbestos deposit 64
Normative compositions
Allerston talc-magnesite deposit 28
Daffodil deposit 40
Garrison asbestos deposit 58
Munro asbestos deposit 64
Sequence of veining 72
Timmins area 7
Dunite, asbestos-bearing 70
Chemical analyses
Slade-Forbes asbestos deposit 45
Normative compositions
Slade-Forbes asbestos deposit 45

Dunite, carbonate-altered
Chemical analyses
Allerston talc-magnesite deposit ... 31
Canadian Magnesite Mines Ltd. ... 14
Munro asbestos deposit ... 64,66
Microprobe analyses
Canadian Magnesite Mines Ltd. ... 13,20
Modal analyses
Canadian Magnesite Mines Ltd. ... 16
Normative compositions
Allerston talc-magnesite deposit ... 31
Munro asbestos deposit ... 64
Dunite, serpentinized ... 61,68
Asbestos ... 43,46,57
Carbon & oxygen isotope data ... 75
Chemical analyses
Allerston talc-magnesite deposit ... 31
Daffodil asbestos deposit ... 40
Garrison asbestos deposit ... 58
Munro asbestos deposit ... 64,66
United Asbestos deposit ... 50
Normative compositions
Allerston talc-magnesite deposit ... 31
Daffodil asbestos deposit ... 40
Garrison asbestos deposit ... 58
Munro asbestos deposit ... 64
United Asbestos deposit ... 50
Dunite, talc-carbonate altered
Carbon & oxygen isotope data ... 75
Chemical analyses
Slade-Forbes deposit ... 45
Normative compositions
Slade-Forbes deposit ... 45
Dunitic komatiite ... 11,12,39,48
Carbonation (modal analyses)
Allerston talc-magnesite deposit ... 35
Canadian Magnesite Mines Ltd. ... 35
Mineralogy
Canadian Magnesite Mines Ltd. ... 19
Dunitic komatiite, altered ... 7,9,25
Photo ... 12
Dunitic komatiite, polyhedral breccia ... 38,42
Chemical analyses
Daffodil deposit ... 40
Chrysolite asbestos vein
Photo ... 38
Normative compositions
Daffodil deposit ... 40
Dunitic komatiite, serpentinized
Chemical analyses
Daffodil deposit ... 40
Normative compositions
Daffodil deposit ... 40
Dunitic rock, flows ... 43,47,48,49
East Pit ore zone, United Asbestos ... 49
Exploration
Guidelines ... 79
Fabric
Patchwork
Altered dunitic komatiite ... 13
Fault
Allerston talc-magnesite deposit ... 26
Daffodil asbestos deposit ... 36
Garrison asbestos deposit ... 57
Midlothian Twp. ... 47
Mitt Lake fault ... 48
Munro asbestos deposit ... 61
Munro, Harker & Garrison Twp. ... 53
Slade-Forbes deposit ... 43
Faymar Mine ... 36
Felsite dike ... 43
Feldspar
Pillowed calc-alkalic basalt ... 36
Flintkote Mines Ltd. ... 54
Flows, felsic to intermediate ... 23
Flows, komatiitic ... 25
Flows, mafic ... 23
Flow, ultramafic
Asbestos ... 43,46
Peridotitic spinifex-bearing
Carbonate-alteration ... 12
Timmins area ... 6
Magnesite-talc ... 9
Flow, ultramafic differentiated
Asbestos
Daffodil deposit ... 36,38
Daffodil deposit ... 39
Fluviatile sediments
Porcupine Group
Timmins area ... 6
Folds ... 47,48,50
Allerston talc-magnesite deposit ... 25-26
Asbestos formations ... 73
Munro, Harker & Garrison Twp. ... 53
Timmins area ... 7
Foliations
Allerston deposit ... 25
Forsterite
High CO_2 fluid
Talc-magnesite ... 73
Low CO_2 fluid
Serpentine-magnesite ... 73
Gabbro ... 36,47,48,54
Chemical analyses
Hofmann asbestos deposit ... 55
Munro asbestos deposit ... 64,66
United Asbestos deposit ... 50
Normative compositions
Hofmann asbestos deposit ... 55
Munro asbestos deposit ... 64
United Asbestos deposit ... 50

Gabbro, carbonated
  Chemical analyses
    Munro asbestos deposit 64,66
  Normative compositions
    Munro asbestos deposit 64
Gabbro, leucocratic 57
  Chemical analyses
    Garrison asbestos deposit 58
  Normative compositions
    Garrison asbestos deposit 58
Gabbro-peridotite flow 68
  Chemical analyses
    Munro asbestos deposit 64
  Normative compositions
    Munro asbestos deposit 64
Gabbroic differentiates 49
Gabbroic rock 61,68,70
  Chemical analyses
    Munro asbestos deposit 64
  Normative compositions
    Munro asbestos deposit 64
Garrison (Bird-Ginn) asbestos deposit 57-59,70
  Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
  Chemical analyses 58
  Jensen cation plot 59
  Map
    Location 2
  Normative compositions 58
Garrison-East claim group 57
Garrison-West claim group 57
Garrison Twp.
  Asbestos
    Garrison asbestos deposit 57-59
    Stratigraphic position 53
  Geology 53
Geochemistry
  Serpentinites 73
Ghost Range Sill 53
  Jensen cation plot 56
Glomeroporphyritic texture
  South Zone Allerston deposit 26
Gold
  Deloro Twp. 36,70
Gowganda Formation sedimentary rock 47,48
Granitic intrusions 53
Granitoid pluton 37
Graphite
  Iron formation 25
Grenville
  Dolomite
    Talc 4
  Marble
    Magnesite 4
Griffis, A.T. 7
Gulf Oil 53
Halliday Dome 47,50,79
Harker Twp.
  Asbestos
    Hofmann asbestos deposit 53-56
    Stratigraphic position 53
  Geology 53
Hematite
  Carbonate alteration
    Komatiite 72
  Dunite, highly carbonated 13,20
  Dunitic or peridotitic komatiite, altered 11
  Serpentinization 73
  Talc-magnesite rock 74
  Talc veins 25
Hofmann, C.E. 53
Hofmann asbestos deposit 53-56
  Economic geology 53-54
  Geology 54
  Map
    Location 2
  Mineralogy & chemistry 54
    Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
    Chemical analyses 55
    Jensen cation plot 56
    Normative compositions 55
Hornblende
  Pillowed calc-alkalic basalt 36
  Talc vein 25
Hydration
  Low temperature
    Serpentinization & asbestos formation 72
Hydrothermal, meteoric waters
  Asbestos formation 73
  Talc-magnesite formation 77,78,79
Intrusive rocks
  Allerston deposit 25
Iherzolite
  Timmins area 7
Iron
  Archean magnesite 4
    Canadian Magnesite Mines Ltd. 9,20,21
  Archean talc 4
  Munro-Beatty sill 68
  Pyroxenite 39
Iron Formation
  Deloro Group 6,7
    Allerston talc-magnesite deposit 25
  Trace element concentration
    Canadian Magnesite Mines Ltd. 19
Iron formation, carbonate 70,79
Iron formation, oxide 25
Iron formation, quartz-carbonate 9,11,12
  Trace element analyses
    Canadian Magnesite Mines Ltd. 13,19
Iron formation, quartz-graphite 25
Iron formation, sulphide 25
Jasper
  Iron formation 12

Jensen cation plot 70,74
  Allerston talc-magnesite deposit 34
  Canadian Magnesite Mines Ltd. 20
  Daffodil asbestos deposit 42
  Garrison asbestos deposit 59
  Hofmann asbestos deposit 56
  Munro asbestos deposit 66
  Slade-Forbes asbestos deposit 46
  United Asbestos deposit 52
Johns-Manville Canada Incorp. 57
Jointing
  Polyhedral
    Photo 39
Kilmar, Quebec
  Magnesite 4
Koedoe komatiitic sill
  Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
Komatiite 12,36,74
  Asbestos formation 72-73
    Seawater, low CO_2 78,79
  Carbon & oxygen isotope data 75
  Chemical analyses
    Allerston deposit 28
  Geochemistry 70
  Normative compositions
    Allerston deposit 28
  Talc-magnesite formation 73
    Hydrothermal, meteoric water 12,78,79
Komatiite, basaltic 70
  Tisdale Group 6
    Canadian Magnesite Mines Ltd. 7,12
Komatiite, peridotitic
  Flow
    Magnesite 11
  Mineralogy & chemistry 13
  Serpentinized
    Magnesite-talc 9
  Tisdale Group 7
Komatiite, ultramafic
  Polyhedral jointing
    Photo 39
Komatiite flow, dunitic & peridotitic
  Talc-carbonate alteration
    Stratigraphically controlled 70,72
Komatiitic dunite
  Carbonate-altered
    Magnesite-talc 7,11
    Stratigraphic 12
  Flow
    Magnesite 11
    Photo 12
  Mineralogy & chemistry 13
Komatiitic rocks or sills 48,61,68
  Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
  Allerston talc-magnesite deposit 25
  Canadian Magnesite Mines Ltd. 21
  Lloyd Lake Complex 49
Komatiitic ultramafic rocks
  Archean
    Asbestos 4-5
    Magnesite 4
    Talc 4
Langmuir serpentinites 73
Leuco gabbro, plagioclase-rich
  Gabbro differentiate 49
Lightval Mines Ltd. 53,54
Lizardite 73
Lloyd Lake 47,48
Lloyd Lake Complex 47,48,49
  Jensen cation plot 52
McVeigh claim group 57
Madoc
  Talc 4
Mafic to ultramafic rocks
  Sills and stocks 47
Magnesite
  Allerston Talc-magnesite deposit 22-35
  Archean 4
  Archean ultramafic rock
    Komatiitic 70
  Canadian Magnesite Mines Ltd. 7-21
  Composition 74-75
  Content/Grade/%
    Canadian Magnesite Mines Ltd. 21
  Dunitic or peridotitic komatiite 13
  Formation 73
  Hematite-rutile oxides 20
  Komatiite
    Carbonate altered 70
  Microprobe analyses
    Carbonate 18
    Munro-Beatty sill 66
  Modal analyses
    Allerston deposit 35
    Canadian Magnesite 35
  Munro-Beatty sill 68
  Stratigraphic position
    Timmins area 7
Magnesite rock, white
  Carbon & oxygen isotope data 75
  Chemical analyses
    Canadian Magnesite Mines Ltd. 14
  Modal analyses
    Canadian Magnesite Mines Ltd. 16
  Normative composition
    Canadian Magnesite Mines Ltd. 14

Magnesite-talc rocks
Canadian Magnesite Mines Ltd.
Komatiitic 21
Veins & opaques 72
Magnetite
Asbestos formation 72-73
Asbestos ore 61
Chromite-peridotitic komatiite 20
Dunitic komatiite 25
Dunitic-peridotitic komatiite
Magnesite deposit 11
Iron formation 25
Magnesite 20
Serpentinized dunite 57
Sequence of veining
Dunite-peridotite alteration 70,72
Talc-magnesite rock 74
Major element concentration
Allerston talc-magnesite deposit 28-31
Canadian Magnesite Mines Ltd. 14
Daffodil asbestos deposit 40
Garrison asbestos deposit 58
Hofmann asbestos deposit 55
Munro asbestos deposit 64
Slade-Forbes asbestos deposit 45
United Asbestos deposit 50
Marble, Grenville
Magnesite 4
Maynard Lake 36
Metamorphic grades
Garrison asbestos deposit 57
Munro, Harker & Garrison Twp. 53
Metamorphism
Mild
Asbestos formation 73
Metasediments 47
Porcupine Group
Timmins area 6
Tuffaceous
Gold 36
Metavolcanic rock
Archean
Timmins area 6
Felsic 47
Intermediate 47
Carbonate alteration 12
Intermediate to felsic 53
Intermediate to mafic 61
Mafic to ultramafic 53
Mica
Magnesite deposit 11
Microprobe analyses
see Analyses, microprobe
Midlothian Twp.
Archean komatiites 79
Asbestos
Stratigraphic position 47
United Asbestos deposit 47-52
Geology 47
Mineralogy
Canadian Magnesite Mines Ltd. 19
Mitt Lake fault 48
Modal analyses
see Analyses, modal
Munro asbestos deposit 60-69,72,77
Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
Area I
Cross-section 62
Chemical analyses 66
Geology, mineralogy & chemistry 61,68
Map 63
Microprobe analyses 67
Area II
Geology, mineralogy & chemistry 68
Map 69
Chemical analyses 64
Carbonate alteration Area I 66
Economic geology 61
Jensen cation plot 66
Map
Geology 60,63,69
Location 2
Microprobe analyses 67
Normative compositions 64
Munro-Beatty sill 60,61,68,70
Chemical analyses 64,66
Jensen cation plot 66
Normative compositions 64
Munro group 53
Komatiites 79
Munro Twp. 74
Asbestos
Munro asbestos deposit 60-69
Stratigraphic position 53
Geology 53
Nakhodas asbestos property 36
Nemalite
Asbestos 48
Nepheline
Carbonate-altered ultramafic rock 39
Dioritic differentiate 54
Leucocratic gabbro 57
Nickel
Archean talc 4
Loss
Talc-magnesite 74
Nicolet Asbestos Mines Ltd. 36
Normative Composition
see Analyses, Normative composition
North ore zone, United Asbestos 48
North Zone Allerston deposit 74,77
Chemical analyses 29
Economic geology 23
Geology 23
Mineralogy 26
Modal analyses 26-27,34
Normative compositions 29

Olivine
Komatiite
Asbestos formation 78
Lloyd Lake Complex 49
North Zone Allerston deposit 26
Serpentinite 72
Opaque Minerals
Microprobe analyses
Canadian Magnesite Mines Ltd. 17
Modal analyses
Allerston talc-magnesite deposit 26-27,34
Talc-Magnesite rocks 72,74
Oro Mines Ltd. 23
Oxides
Modal analyses 16
Oxygen isotope data 75-76
Penhorwood Twp.
Archean talc 4,78
Peridotite 47,49,54,61
Basal asbestos-bearing 70
Carbonate alteration
High CO_2 - talc-magnesite 70
Low CO_2 - asbestos 70
Chemical analyses
Allerston talc-magnesite deposit 30
Hofmann asbestos deposit 55
Munro asbestos deposit 64
Loss of constituents 74
Normative compositions
Allerston talc-magnesite deposit 30
Hofmann asbestos deposits 55
Munro asbestos deposit 64
Sequence of veining 72
Peridotite, carbonated
Chemical analyses
Daffodil asbestos deposit 40
Munro asbestos deposit 64
Normative compositions
Daffodil asbestos deposit 40
Munro asbestos deposit 64
Peridotite, serpentinized
Asbestos 36,38,53,61
Chemical analyses
Allerston talc-magnesite deposit 31
Munro asbestos deposit 64
Normative compositions
Allerston talc-magnesite deposit 31
Munro asbestos deposit 64
Peridotite, tholeiitic 70
Peridotitic komatiite 11,12,68
Carbon & oxygen isotope data 75
Chemical analyses
Allerston talc-magnesite deposit 28,30,31,35
Canadian Magnesite Mines Ltd. 14
Daffodil asbestos deposit 40
Garrison asbestos deposit 58
Hofmann asbestos deposit 55
Munro asbestos deposit 64
Slade-Forbes asbestos deposit 45
United Asbestos deposit 50
Chromite 20
Microprobe analyses of opaques
Canadian Magnesite Mines Ltd. 17
Mineralogy
Canadian Magnesite Mines Ltd. 19
Modal Analyses
Allerston talc-magnesite deposit 27
Canadian Magnesite Mines Ltd. 16
Normative compositions
Allerston talc-magnesite deposit 28,30,31
Canadian Magnesite Mines Ltd. 14
Daffodil asbestos deposit 40
Garrison asbestos deposit 58
Hofmann asbestos deposit 55
Munro asbestos deposit 64
Slade-Forbes asbestos deposit 45
United Asbestos deposit 50
Peridotitic komatiite, serpentinized 9
Peridotitic komatiite, carbonate-altered
Carbon & oxygen isotope data 75
Chemical analyses
Canadian Magnesite Mines Ltd. 14
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative composition
Canadian Magnesite Mines Ltd. 14
Pillows
Basalt 12
Calc-alkalic 36
Porcupine Group
Timmins area 6
Porphyry
see Quartz-feldspar porphyry
Pressure
Low
Talc-magnesite formation 73
Production
Asbestos 5
Canada Talc Ind. Ltd. 4
Steetley Talc Ltd. 4
Talc 4
Prograde environment
Asbestos formation 72,73
Pyrite
Iron formation 12,25
Magnesite deposit 11
Pyroaurite-brugnatellite
Asbestos 48

Pyroclastics
Deloro Group 6,7
Allerston deposit 23
Iron formation 25
Pyroxene
Serpentinite 72
Pyroxenite 36,47,48,54,61
Chemical analyses
Daffodil asbestos deposit 40
Hofmann asbestos deposit 55
United Asbestos deposit 50
Gabbro differentiate 49
Normative compositions
Daffodil asbestos deposit 40
Hofmann asbestos deposit 55
United Asbestos deposit 50
Pyroxenitic rock 70
Pyrrhotite
Iron formation 25
Quartz
Allerston talc-magnesite deposit 35
Calc-alkalic basalt or andesite 23
Canadian Magnesite Mines Ltd. 11,21
Dunitic komatiite 13
Magnesite formation 73
Modal analyses
Allerston deposit 35
Canadian Magnesite 16,35
Quartz-carbonate vein
Carbonate
Microprobe analyses 18
Quartz-feldspar porphyry
Timmins area 7
Quartz-sericite-chlorite schist 23
Quartz-sericite schist 23
Quartz veins
Carbonate alteration
Komatiite 72
Dunitic komatiitic flow
Photo 12
Reducing environment
Serpentinization & asbestos formation 72
Retrograde environment
Asbestos formation 72-73
Rhyodacite 23
Rhyolite
Hofmann asbestos deposit 54
Rhyolite Lake 47
Rhyolitic pyroclastics & flows
Deloro Group 6
Allerston talc-magnesite deposit 7,23
Rhyolitic rocks 47
Rodingite dike 49
Rosario Resources Canada Ltd. 22,23
Round Lake granitic batholith 47
Rutile
Carbonate alteration
Komatiite 72
Dunite, highly carbonated 13,20
Magnesite deposit 11
Talc-magnesite rock 74
Saccharoidal texture
South Zone Allerston deposit 26
Seawater, altering fluid
Carbonate alteration
Komatiite 12,70
Komatiitic differentiated sill
Asbestos formation 73,77,78,79
see also Hydrothermal, meteoric water
Serpentine
Dunitic or peridotitic komatiite 13
Modal analyses
Canadian Magnesite Mines Ltd. 16
Serpentinization & asbestos formation 72,73
Serpentinite 47
Asbestos 36
Magnetite 70
Veins & opaques 72
Serpentinization 72-73
Archean ultramafic rock 70
Timing of alteration 77
see also Asbestos formation
Shaw Dome
Timmins area 7,11
Shear zone 57
see also Faults
Silica
South Zone Allerston deposit 26
Siliceous rock, chloritic
Chemical analyses
Canadian Magnesite Mines Ltd. 14
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative composition
Canadian Magnesite Mines Ltd. 14
Sill or stock, mafic to ultramafic
Midlothian Twp. 47
Timmins area 7
Sill or flow, differentiated mafic to ultramafic
Asbestos 48,53,54,61
Silver
Iron formation 25
Slade-Forbes asbestos deposit 43-46,70,77
Carbon & oxygen isotope data 75,76
Economic geology 43
Geology 43
Map 44
Map
Geology 44
Location 2,6,8
Stratigraphic position 7
Mineralogy & chemistry 43,45,46

Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
Chemical analyses 45
Jensen cation plot 46
Normative compositions 45
South ore zone, United Asbestos 48
South Zone Allerston deposit
Chemical analyses 29,30,31
Economic geology 23
Geology 23
Mineralogy 26
Modal analyses 26-27,34
Normative compositions 29,30,31
Spinel
Microprobe analyses
Munro asbestos deposit 67
Spinifex 70
Chemical analyses
Daffodil asbestos deposit 40
Slade-Forbes asbestos deposit 45
Chromite 74
Normative compositions
Daffodil asbestos deposit 40
Slade-Forbes asbestos deposit 45
Olivine 48,49
Texture
Komatiite 11,12,21,36
Spinifex, altered
Chemical analyses
Canadian Magnesite Mines Ltd. 14
Microprobe analyses of opaques
Canadian Magnesite Mines Ltd. 17
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative composition
Canadian Magnesite Mines Ltd. 14
Spinifex, carbonate-altered
Chemical analyses
Canadian Magnesite Mines Ltd. 14
Microprobe analyses of opaques
Canadian Magnesite Mines Ltd. 17
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative composition
Canadian Magnesite Mines Ltd. 14
Steel industry
Magnesite 4
Steetley Talc Ltd. 4,23,78
Stolzburg komatiitic sill
Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
Stoughton-Roquemaure Group 53
Sulphides
Iron formation 25
Talc
Allerston talc-magnesite deposit 22-35
Archean 4-5
Komatiitic ultramafic rock 70
Canadian Magnesite Mines Ltd. 7-21
Formation 73
Hematite-rutile oxides 20
Komatiite
Carbonate altered 70,72
Dunitic or peridotitic 13
Modal analyses
Allerston talc-magnesite deposit 26-27,34,35
Canadian Magnesite Mines Ltd. 16,35
Production 4
Stratigraphic position
Timmins area 7
Talc-carbonate rock 43,61
Chemical analyses
Slade-Forbes deposit 45
Normative compositions
Slade-Forbes deposit 45
Talc-carbonate alteration
Dunitic & peridotitic komatiite flow 73
Stratigraphically controlled 70,72
Talc-chlorite rock
Chemical analyses
Canadian Magnesite Mines Ltd. 14
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative composition
Canadian Magnesite Mines Ltd. 14
Talc-magnesite
Formation 73
Hydrothermal, meteoric water 78,79
Timing of alteration 77
Veins & opaques 72
Talc-magnesite rock
Carbon & oxygen isotope data 75
Chemical analyses
Allerston deposit 28,29,35
Modal analyses
Allerston deposit 26,27
Normative compositions
Allerston deposit 28,29
Talc-magnesite rock, altered
Chemical analyses
Allerston deposit 28
Normative compositions
Allerston deposit 28
Temperature
Low formation
Asbestos 73
Tholeiite, Mg
Tisdale Group 7

Tholeiitic sills 70
  Al_2O_3 vs FeO*/(FeO* + MgO) plot 71
Thrusting
  see Faults
Timmins area
  Asbestos
    Daffodil asbestos deposit 36-42
    Slade-Forbes asbestos deposit 37-46
    Stratigraphic position 7
  Geology 6-7
    Map 8
  Magnesite
    Allerston Talc-Magnesite Deposit 22-35
    Canadian Magnesite Mines Ltd. 7-21
    Stratigraphic position 7
  Talc
    Allerston Talc-Magnesite Deposit 22-35
    Canadian Magnesite Mines Ltd. 7-21
    Stratigraphic position 7
TiO_2
  Loss
    Talc-magnesite rock 74
TiO_2 vs SiO_2 74
Tisdale Group
  Timmins area 6
    Canadian Magnesite Mines Ltd. 7
Trace element concentration
  Allerston talc-magnesite deposit 28,29,31
  Canadian Magnesite Mines Ltd. 14
    Iron formation 13,19
  Daffodil asbestos deposit 40
  Garrison asbestos deposit 58
  Hofmann asbestos deposit 55
  Munro asbestos deposit 64
  Slade-Forbes asbestos deposit 45
  United Asbestos deposit 50
Tuff, argillaceous 12
  Trace element concentrations
    Canadian Magnesite Mines Ltd. 19
Tuff, argillaceous pyritic
  Chemical analyses
    Canadian Magnesite Mines Ltd. 14
  Modal analyses
    Canadian Magnesite Mines Ltd. 16
  Normative composition
    Canadian Magnesite Mines Ltd. 14
Tuff, carbonaceous pyritic 12
Tuff, graphitic pyritic
  Trace element concentration
    Canadian Magnesite Mines Ltd. 19
Tuff, felsic
  Quartz sericite schist
    Chemical analyses
      Allerston talc-magnesite deposit 31
    Normative compositions
      Allerston talc-magnesite deposit 31
Tuff, felsic to intermediate 23
Tuff, intermediate
  Andesitic
    Chemical analyses
      Allerston talc-magnesite deposit 31
    Normative compositions
      Allerston talc-magnesite deposit 31
Tuff, lapilli
  Deloro Group 7
  Quartz-crystal 12
Tuff, metasediment
  Gold 36
Turbidite
  Porcupine Group
    Timmins area 6
Ultramafic flow rock
  Asbestos
    Daffodil deposit 36
  Carbonate-altered 39
  Deloro Group 6
    Talc, magnesite & asbestos 7
  Differentiated
    Asbestos 48
  Komatiitic 13
  see also Komatiitic ultramafic rock
United Asbestos deposit 47-52
  Economic geology 48
  Geology 48-49
  Map
    Location 2
  Mineralogy & Chemistry 49-52
    Al_2O_3 vs FeO*/(FeO* + MgO) 71
    Chemical analyses 50
    Jenson cation plot 52
    Normative compositions 50
United Asbestos Incorp. 36,47
Veining, sequence of
  Dunite-peridotite alteration 70,72
Volcanic rock
  Allerston talc-magnesite deposit 23
  see also Metavolcanic rocks
Volcanic rock, altered intermediate
  Chemical analyses
    Canadian Magnesite Mines Ltd. 14
  Modal analyses
    Canadian Magnesite Mines Ltd. 16
  Normative composition
    Canadian Magnesite Mines Ltd. 14

Volcanic rock, carbonate-altered
Chemical analyses
Canadian Magnesite Mines Ltd. 14
Modal analyses
Canadian Magnesite Mines Ltd. 16
Normative composition
Canadian Magnesite Mines Ltd. 14
Volcanic vents
see Hydrothermal, meteoric waters
West Pit ore zone, United Asbestos 49
Whitney Twp.
Allerston talc-magnesite deposit 22-35
Archean talc 4
Xenolith
Calc-alkaline andesite 49
Zoning
Compositional
Magnesite deposit 11
Iron
Magnesite grains 20

Chart A
Talc, Magn
Deposits of
Figures 5, 9

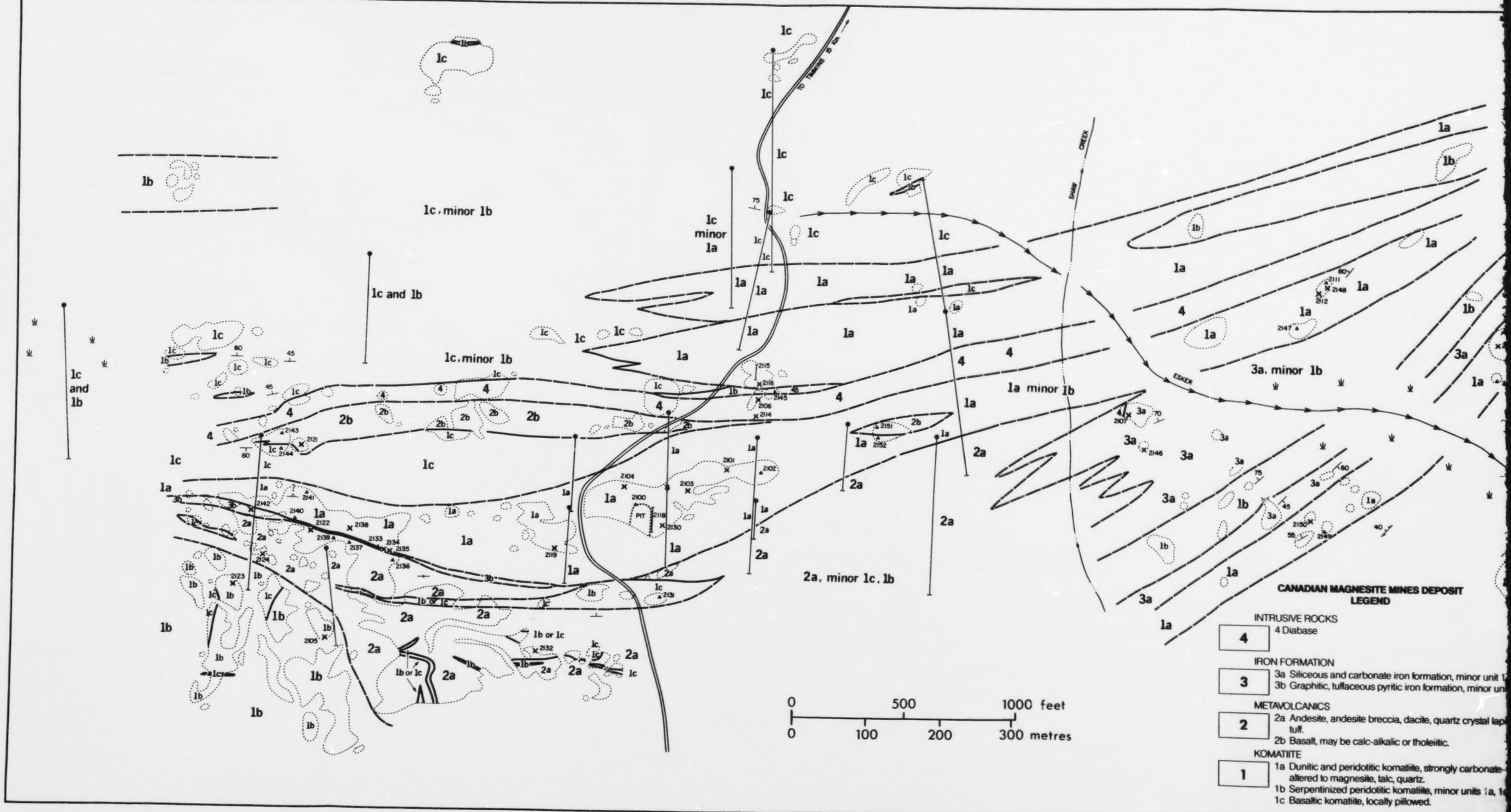


Figure 5. Geology and sample locations, Canadian Magnesite Mines magnesite-talc

Chart A
Talc, Magnesite and Asbestos
Deposits of N. Ontario.
Figures 5, 9, 13

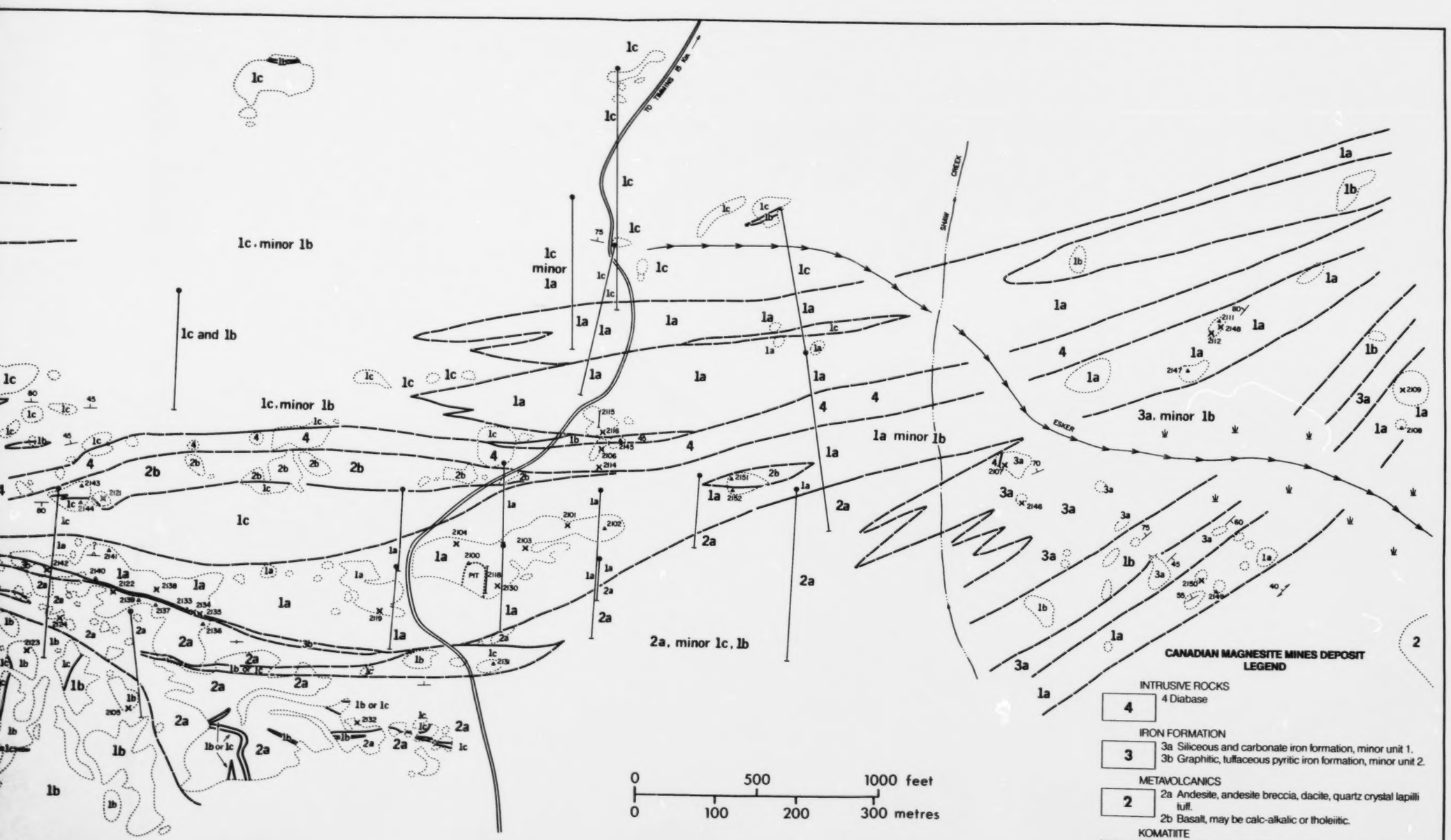


Figure 5. Geology and sample locations, Canadian Magnesite Mines magnesite-talc deposit. Geology by H. Kretschmar, using base map by Canadian Magnesite Mines.

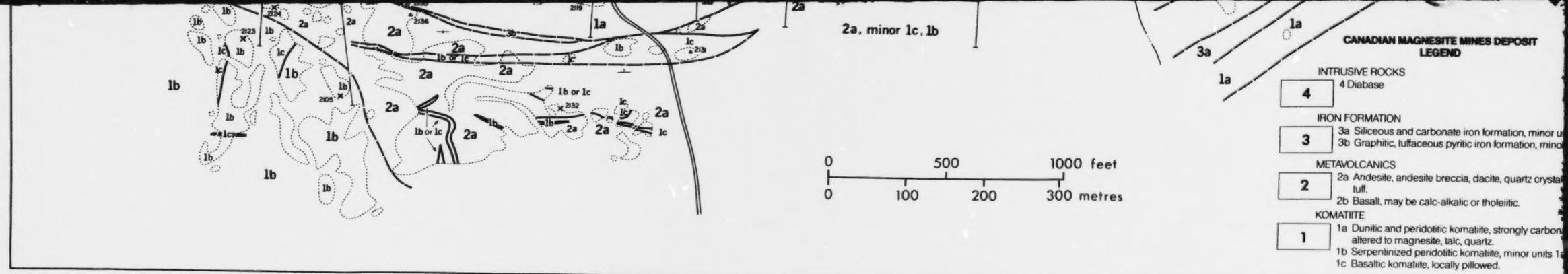
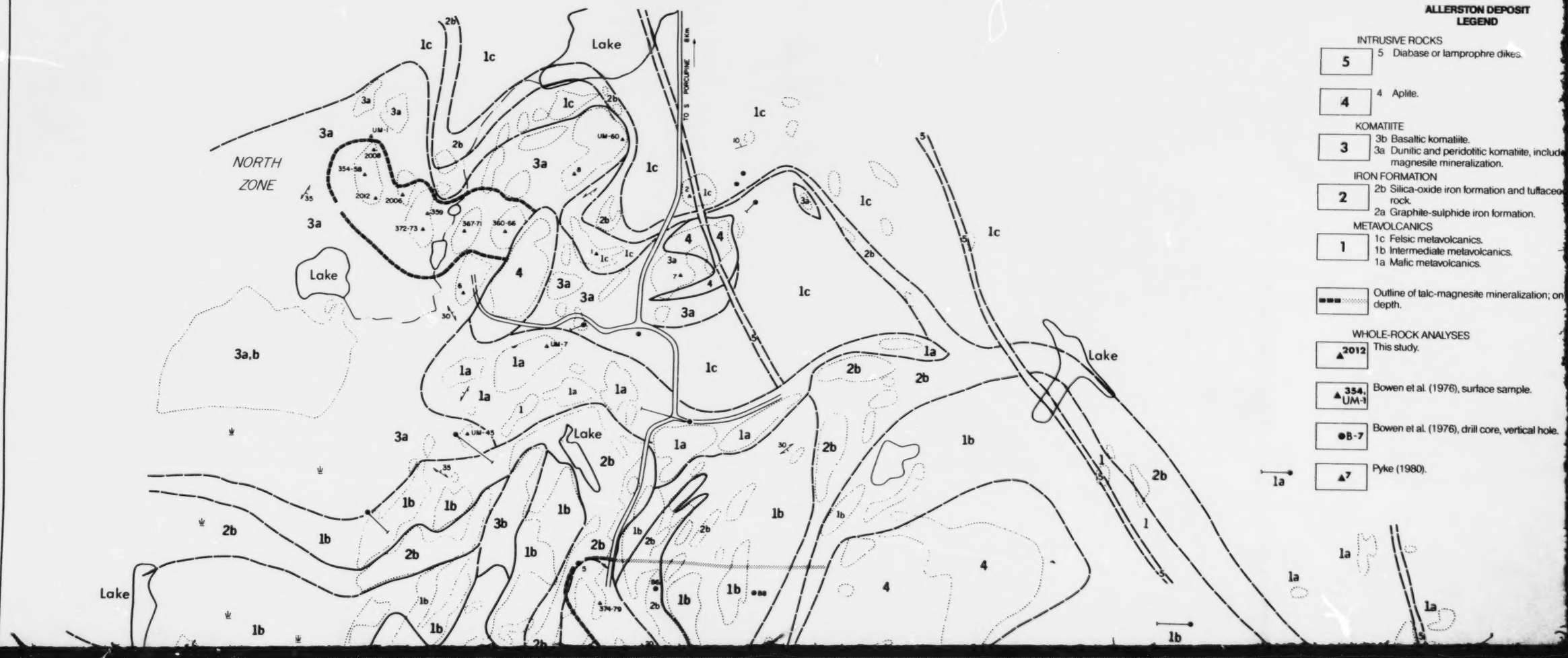

2a, minor 1c, 1b
0 500 1000 feet
0 100 200 300 metres
CANADIAN MAGNESITE MINES DEPOSIT
LEGEND
INTRUSIVE ROCKS
4 Diabase
IRON FORMATION
3a Siliceous and carbonate iron formation, minor u
3b Graphitic, tuffaceous pyritic iron formation, mino
METAVOLCANICS
2a Andesite, andesite breccia, dacite, quartz crysta
tuff.
2b Basalt, may be calc-alkalic or tholeiitic.
KOMATIITE
1a Dunitic and peridotitic komatiite, strongly carbon
altered to magnesite, talc, quartz.
1b Serpentinized peridotitic komatiite, minor units 1
1c Basaltic komatiite, locally pillowed.

Figure 5. Geology and sample locations, Canadian Magnesite Mines magnesite-talc deposit. Geology by U. Kretschmar, using base map by Canadian Magnesite Mines Limited.



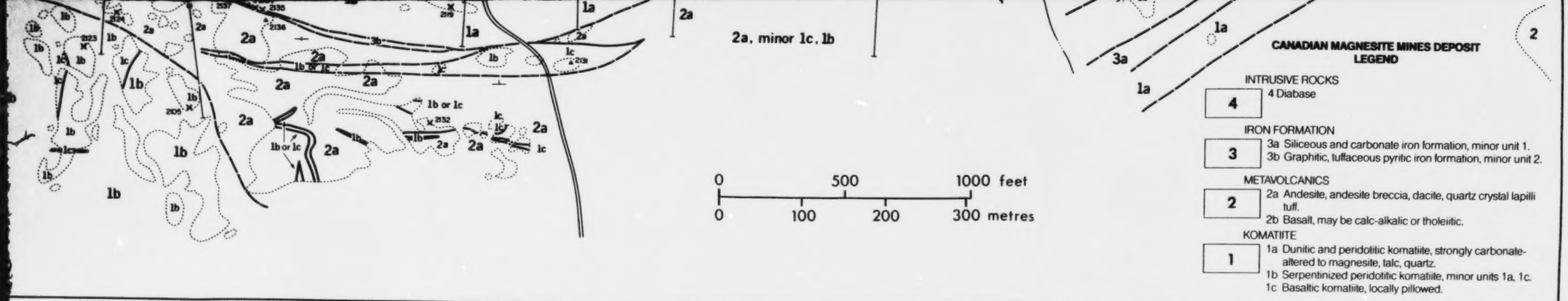
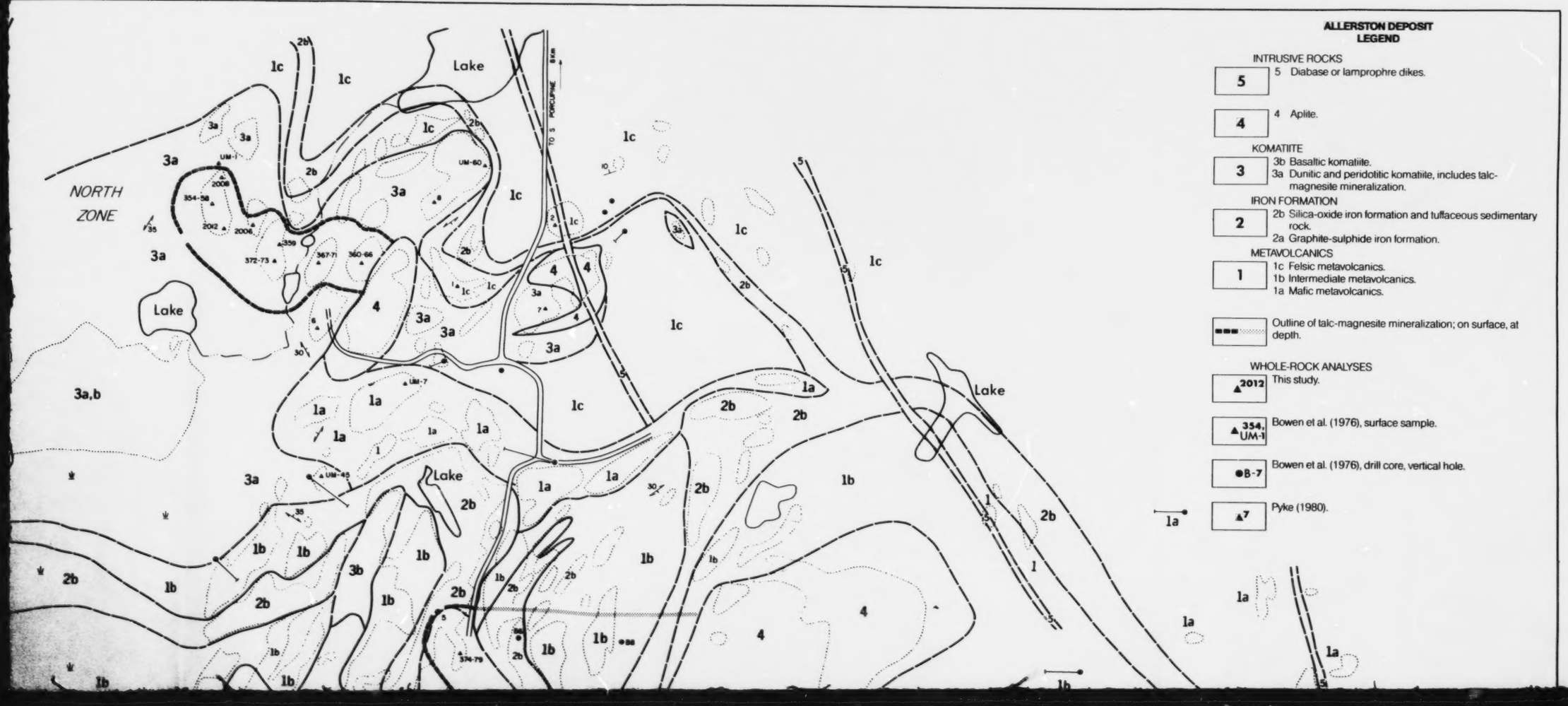

2a, minor 1c, 1b
0 500 1000 feet
0 100 200 300 metres
CANADIAN MAGNESITE MINES DEPOSIT
LEGEND
INTRUSIVE ROCKS
4 Diabase
IRON FORMATION
3a Siliceous and carbonate iron formation, minor unit 1.
3b Graphitic, tuffaceous pyritic iron formation, minor unit 2.
METAVOLCANICS
2a Andesite, andesite breccia, dacite, quartz crystal lapilli tuff.
2b Basalt, may be calc-alkalic or tholeiitic.
KOMATIITE
1a Dunitic and peridotitic komatiite, strongly carbonate-altered to magnesite, talc, quartz.
1b Serpentinized peridotitic komatiite, minor units 1a, 1c.
1c Basaltic komatiite, locally pillowed.

Figure 5. Geology and sample locations, Canadian Magnesite Mines magnesite-talc deposit. Geology by U. Kretschmar, using base map by Canadian Magnesite Mines Limited.



1a Mafic metavolcanics.
Outline of talc-magnesite mineralization; on depth.
WHOLE-ROCK ANALYSES
2012 This study.
354, UM-1 Bowen et al. (1976), surface sample.
B-7 Bowen et al. (1976), drill core, vertical hole.
7 Pyke (1980).
Lake
SOUTH ZONE
0 500 1000 feet
0 100 200 300 metres

Figure 9. Geology and sample locations, Allerston talc-magnesite deposit. Geology after Bowen et al. (1976) and unpublished data of Rosario Resources Limited, modified by U. Kretschmar and D. Kretschmar.

1b Intermediate metavolcanics.
1a Mafic metavolcanics.

Outline of talc-magnesite mineralization; on surface, at depth.

WHOLE-ROCK ANALYSES

▲2012 This study.

▲354, UM-1 Bowen et al. (1976), surface sample.

●B-7 Bowen et al. (1976), drill core, vertical hole.

▲7 Pyke (1980).

Lake

SOUTH ZONE

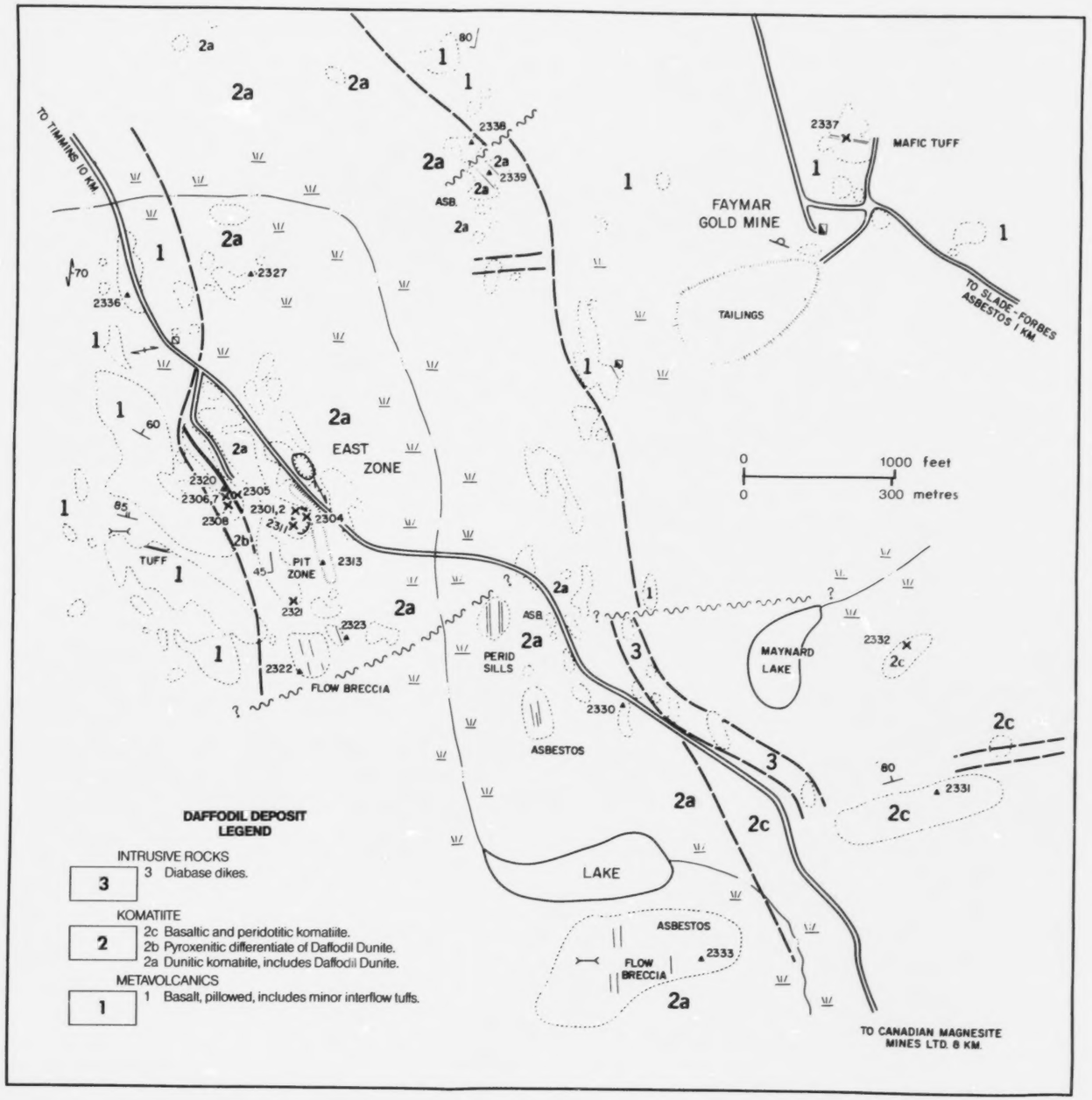
0 500 1000 feet
0 100 200 300 metres

Figure 9. Geology and sample locations, Allerston talc-magnesite deposit. Geology after Bowen et al. (1976) and unpublished data of Rosario Resources Limited, modified by U. Kretschmar and D. Kretschmar.

SYMBOLS

Strike and dip of bedding; inclined, vertical.

Kretschmar and D. Kretschmar.



SYMBOLS

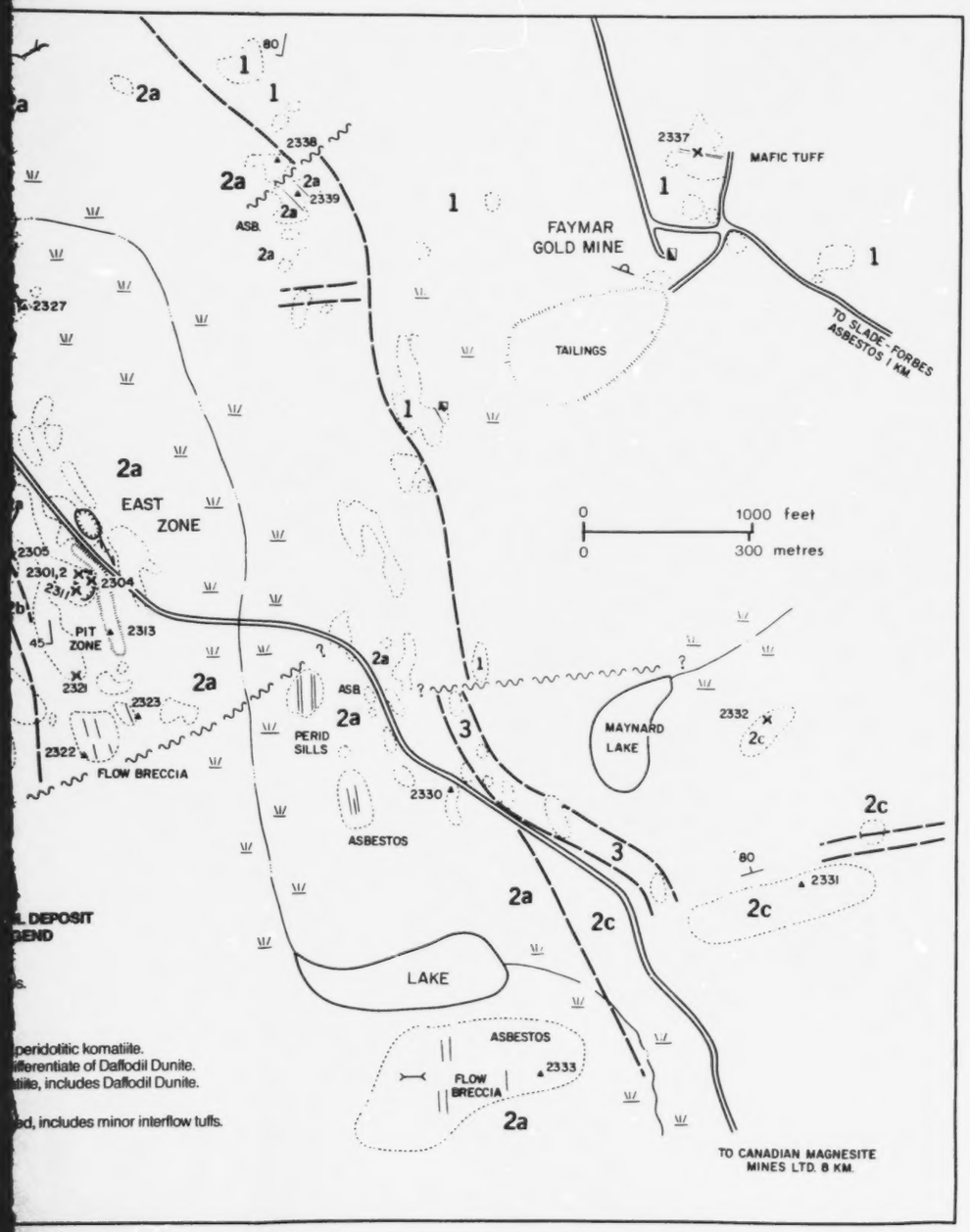
- Strike and dip of bedding; inclined, vertical.
- Strike and dip of foliation; inclined, vertical.
- Geological contact; known, inferred.
- Area of bedrock outcrop.
- Strike and dip of jointing; inclined vertical.
- Top determination from shape of pillows.
- Top determination from spinifex texture.
- Top determination from interflow tuffs.
- Fault; known, inferred.
- Swamp.
- Diamond drill hole; inclined, vertical.
- Banding and direction of asbestos veining.
- Trench.
- Open pit.
- Shaft.
- Tailings dump.

Samples

- Thin section.
- Whole-rock analysis.
- Drill core sample.

Figure 13. Geology and sample locations, Daffodil asbestos deposit. Geology by U. Kretschmar and D. Kretschmar.

Kretschmar and D. Kretschmar.



N

SYMBOLS

- Strike and dip of bedding; inclined, vertical.
- Strike and dip of foliation; inclined, vertical.
- Geological contact; known, inferred.
- Area of bedrock outcrop.
- Strike and dip of jointing; inclined vertical.
- Top determination from shape of pillows.
- Top determination from spinifex texture.
- Top determination from interflow tuffs.
- Fault; known, inferred.
- Swamp.
- Diamond drill hole; inclined, vertical.
- Banding and direction of asbestos veining.
- Trench.
- Open pit.
- Shaft.
- Tailings dump.

Samples

- 2804 — Thin section.
- 2802 — Whole-rock analysis.
- M-21 / 2827 — Drill core sample.

Figure 13. Geology and sample locations, Daffodil asbestos deposit. Geology by U. Kretschmar and D. Kretschmar.

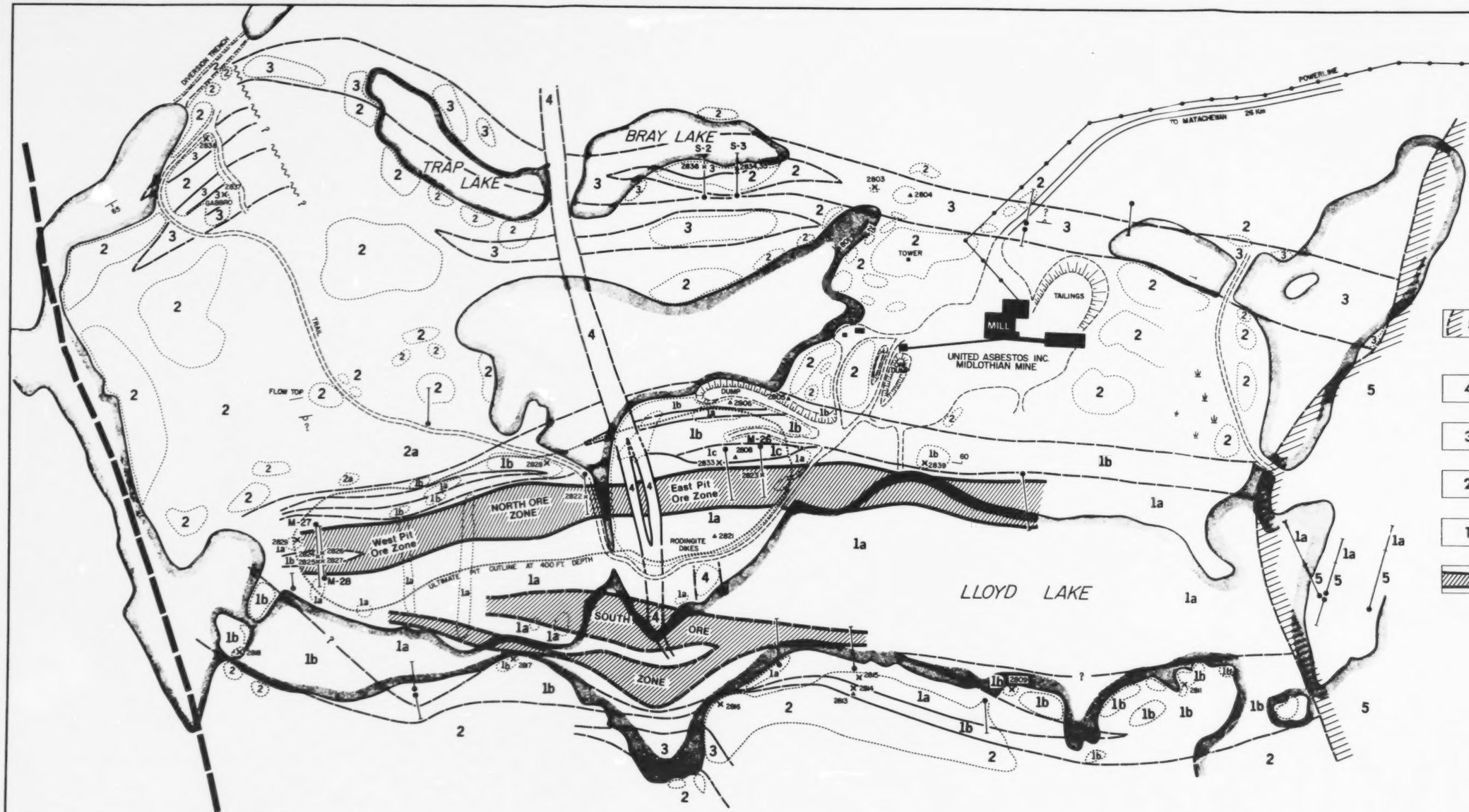


Figure 17. Geology and sample locations, United Asbestos deposit, Midlothian Township. Geology by U. Kretschmar, using base map by J. Hagan, United Asbestos Incorporated, and peripheral geology from E. Bright (1970).

Chart B
Talc, Magnesite and Asbestos
Deposits of N. Ontario.
Figures 17, 19, 21

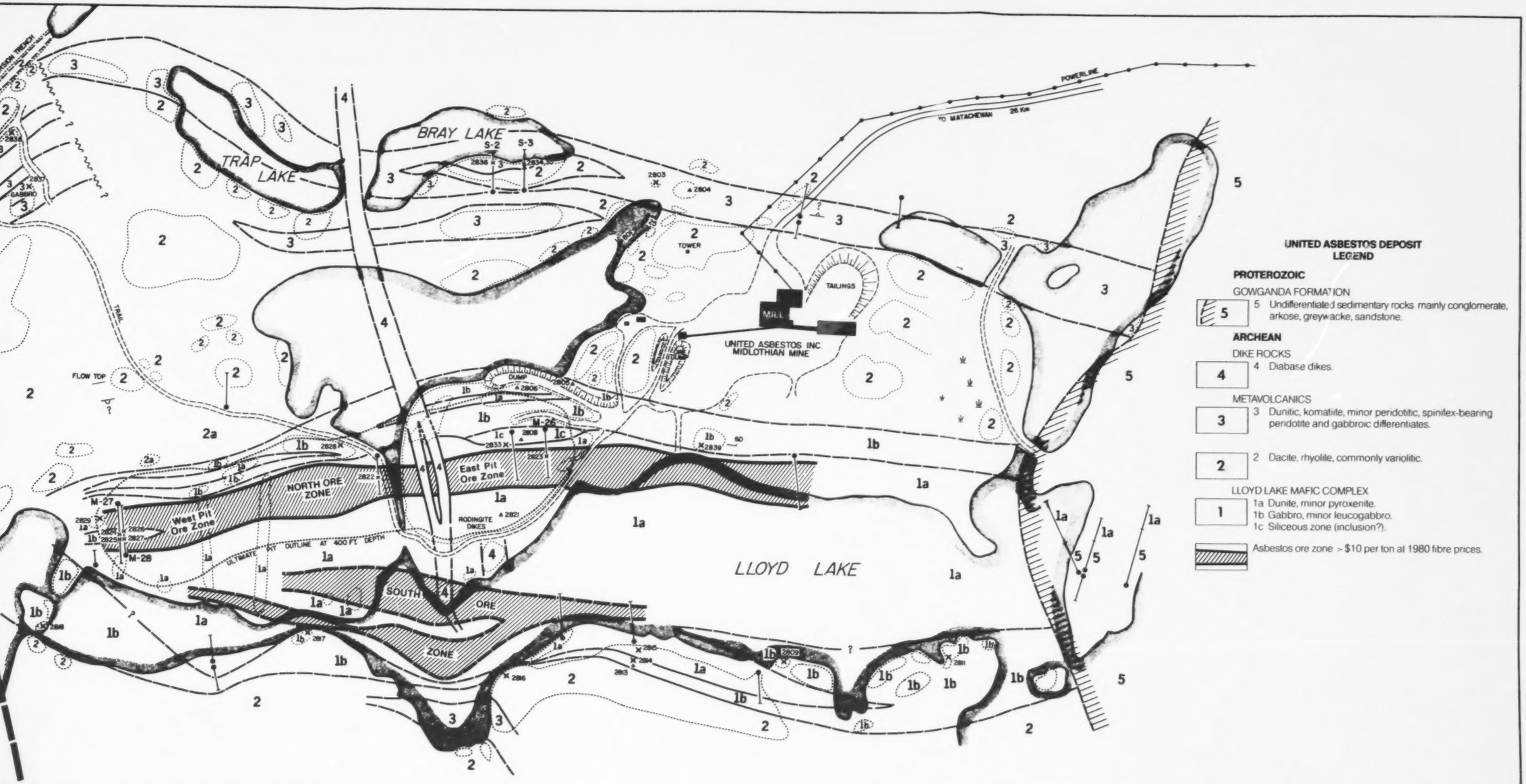


Figure 17. Geology and sample locations, United Asbestos deposit, Midlothian Township. Geology by U. Kretschmar, using base map by J. Hagan, United Asbestos Incorporated, and peripheral geology from E. Bright (1970).

Figure 17. Geology and sample locations, United Asbestos deposit, Midlothian Township. Geology by U. Kretschmar, using base map by J. Hagan, United Asbestos Incorporated, and peripheral geology from E. Bright (1970).

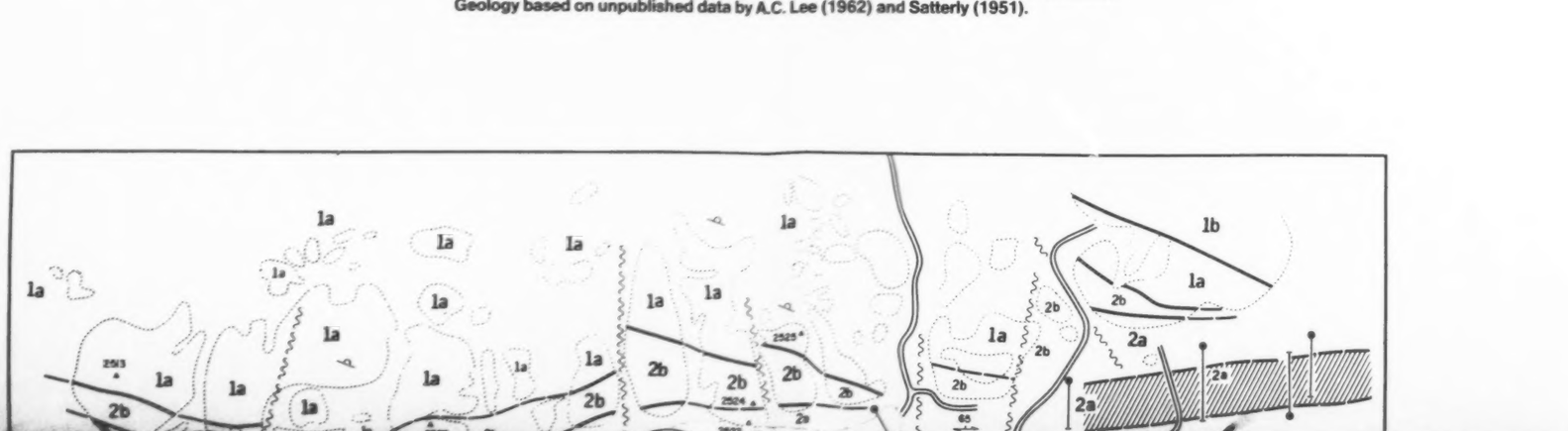


Figure 19. Geology and sample locations, Hofmann asbestos deposit, Harker Township. Geology based on unpublished data by A.C. Lee (1962) and Satterly (1951).

Figure 17. Geology and sample locations. United Asbestos deposit, Midlothian Township. Geology by U. Kretschmar, using base map by J. Hagan, United Asbestos Incorporated, and peripheral geology from E. Bright (1970).

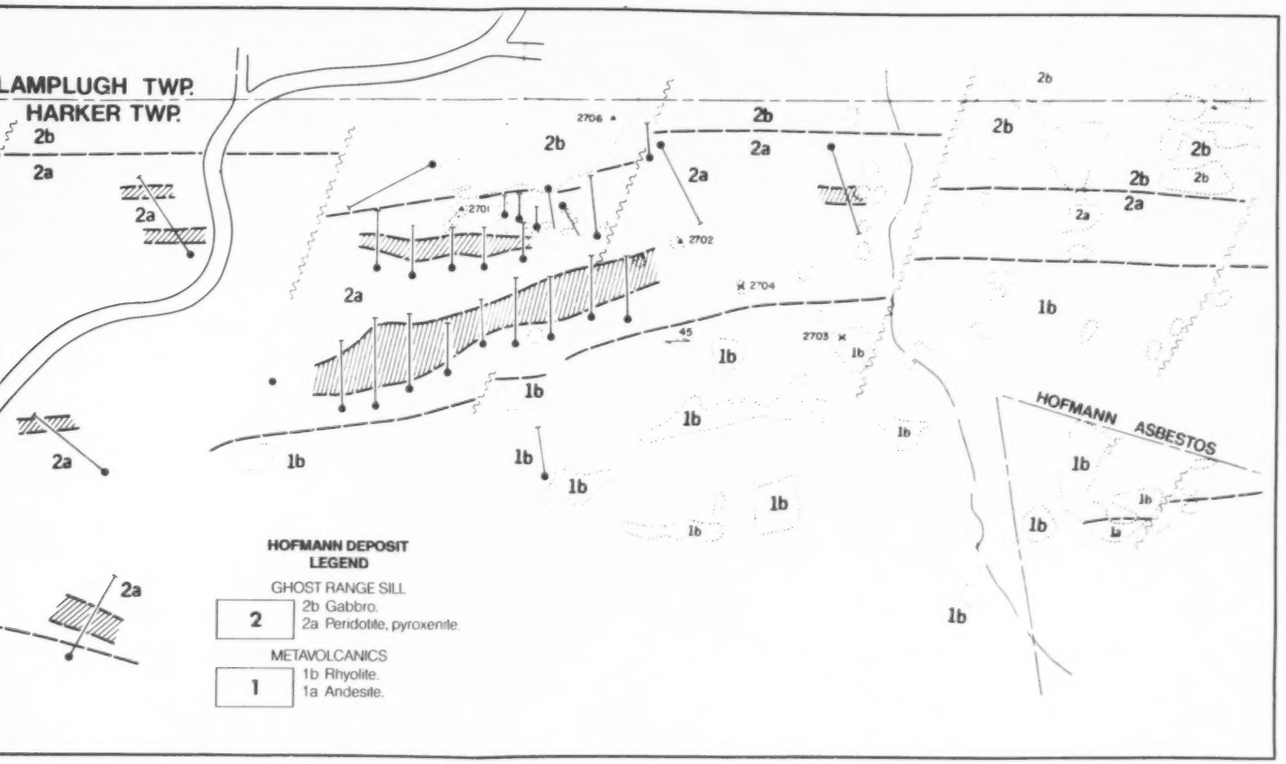
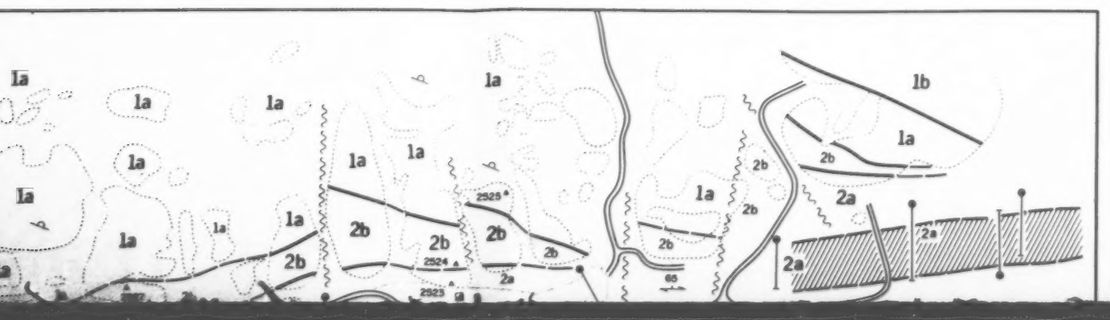


Figure 19. Geology and sample locations, Hofmann asbestos deposit, Harker Township. Geology based on unpublished data by A.C. Lee (1962) and Satterly (1951).



SYMBOLS

- Strike and dip of bedding; inclined, vertical.
- Strike and dip of foliation; inclined, vertical.
- Geological contact; known, inferred.
- Area of bedrock outcrop.
- Strike and dip of jointing; inclined vertical.
- Top determination from shape of pillows.
- Top determination from spinifex texture.
- Top determination from interflow tuffs.
- Fault; known, inferred.
- Swamp.
- Diamond drill hole; inclined, vertical.
- Banding and direction of asbestos veining.
- Trench.
- Open pit.
- Shaft.
- Tailings dump.

Samples

- Thin section.
- Whole-rock analysis.

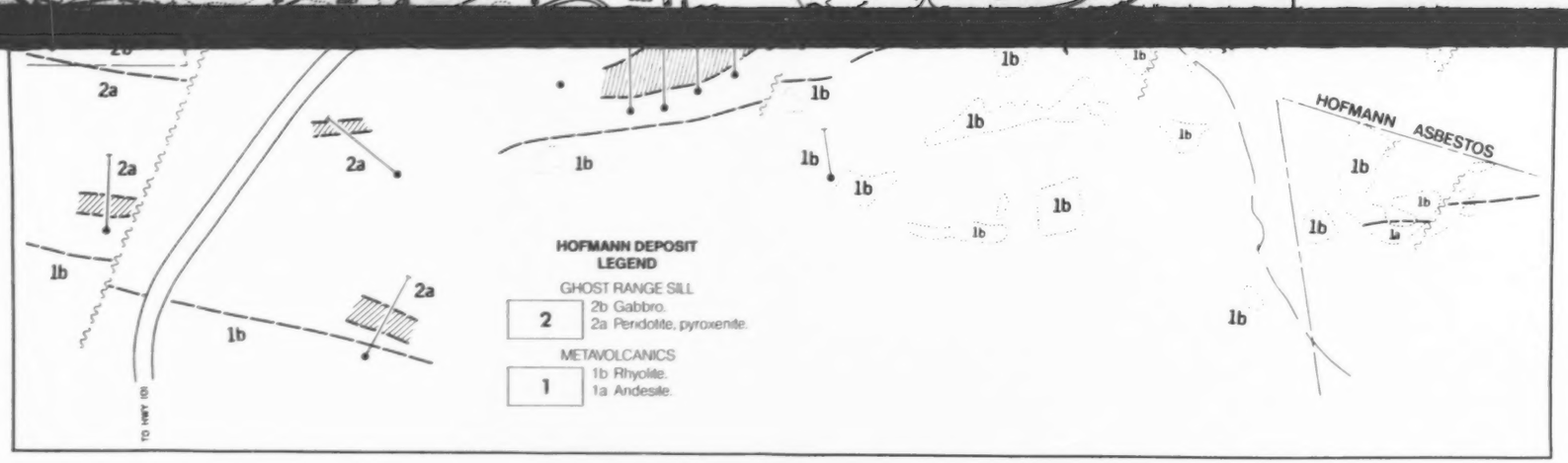
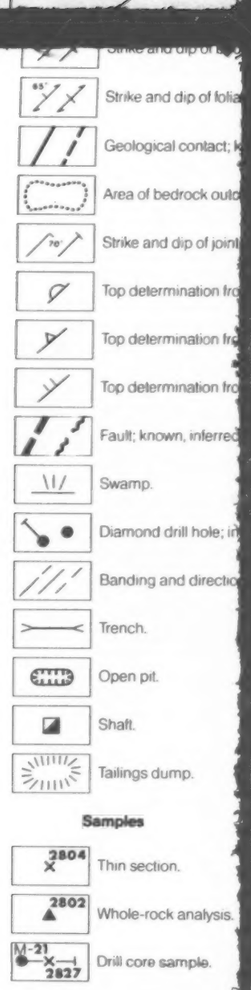


Figure 19. Geology and sample locations, Hofmann asbestos deposit, Harker Township. Geology based on unpublished data by A.C. Lee (1962) and Satterly (1951).



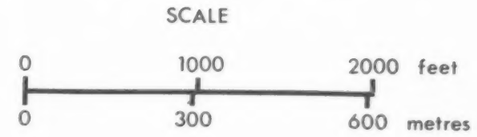


Figure 21. Geology and sample locations, Garrison (Bird-Ginn) asbestos deposit, Garrison Township. Geology compiled from Satterly (1949) and Ploeger and Grabowski (1979).

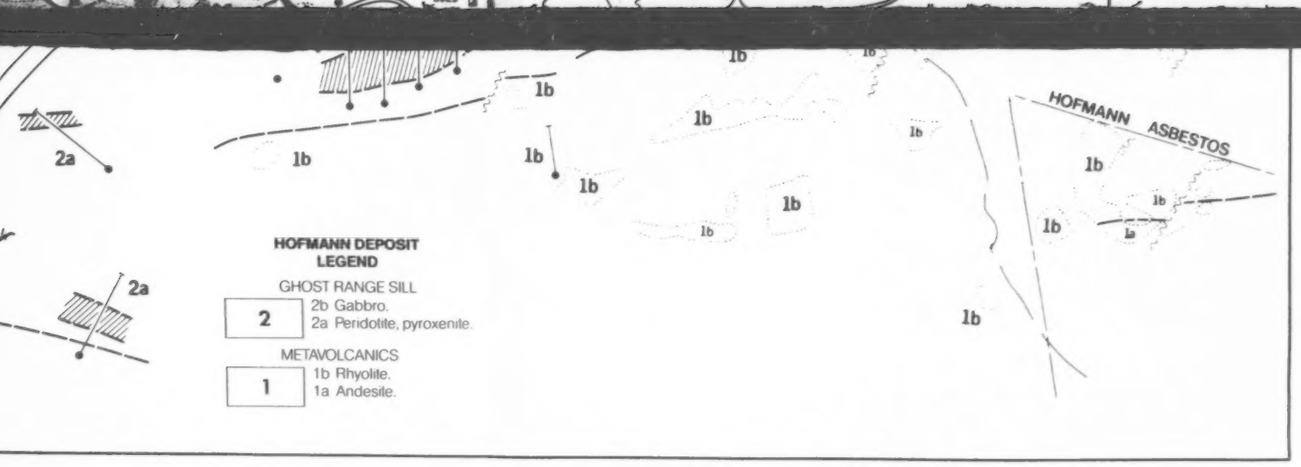


Figure 19. Geology and sample locations, Hofmann asbestos deposit, Harker Township. Geology based on unpublished data by A.C. Lee (1962) and Satterly (1951).

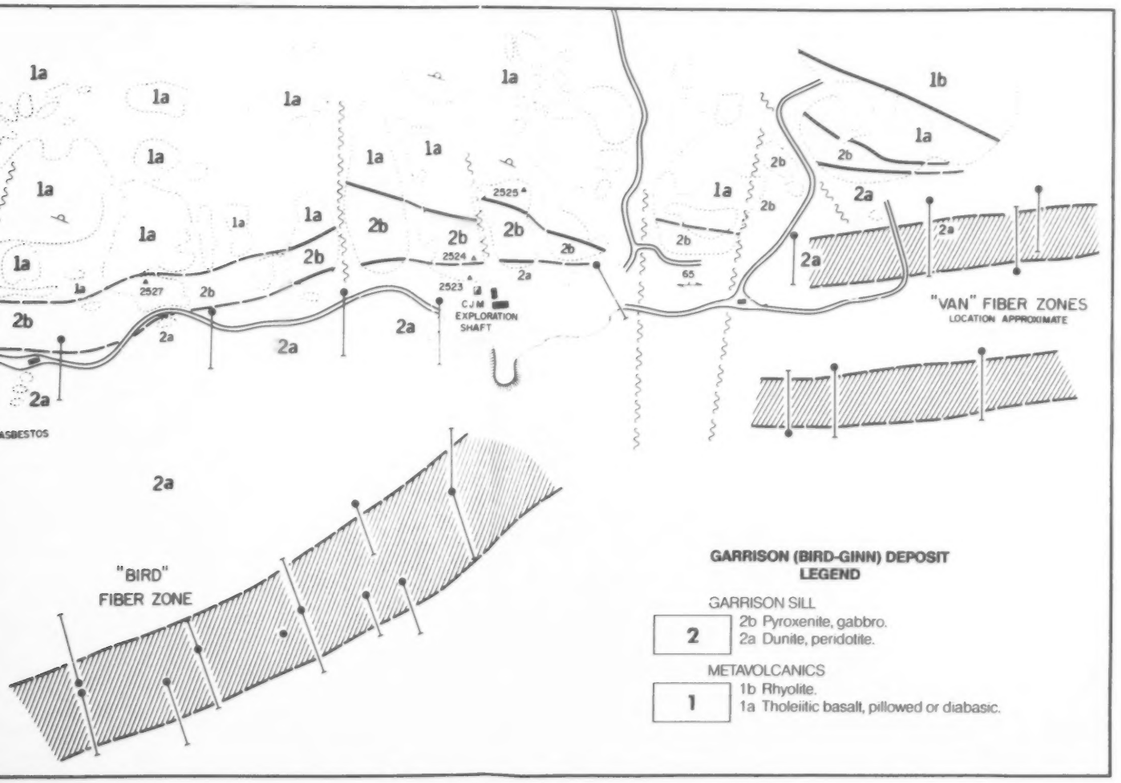
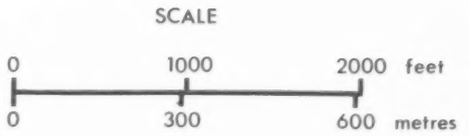



Figure 21. Geology and sample locations, Garrison (Bird-Ginn) asbestos deposit, Garrison Township. Geology compiled from Satterly (1949) and Ploeger and Grabowski (1979).